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TRAINEE AND INSTRUCTOR TASK QUANTIFICATION: DEVELOPMENT OF QUANTITATIVE INDICES AND A PREDICTIVE METHODOLOGY

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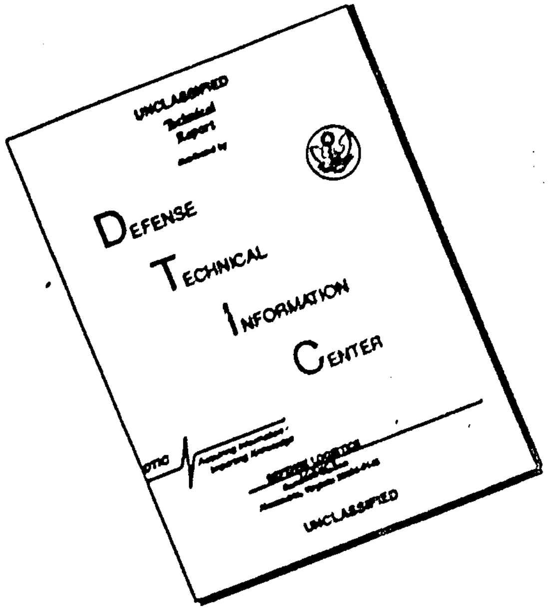

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ABSTRACT

An exploratory study was undertaken, as part of a program to develop quantitative techniques for prescribing the design and use of training systems. As a first step in this program, the present study attempted to: (1) compile an initial set of quantitative indices, (2) determine whether these indices could be used to describe a sample of trainee tasks and differentiate among them, (3) develop a predictive methodology based upon the indices, and (4) assess that methodology.

The compilation included the Display-Evaluative Index, a set of panel lay-out indices, and a set of task rating scales. These indices were applied to task analytic data, collected on sonar operator trainers at Fleet Sonar School, Key West, Florida. Application of the indices proved feasible, and differentiation among three training devices, and within four trainee sub-tasks (set-up, detection, localization, classification) was possible.

The predictive method which was generated was an adaptation of the standard multiple regression model. Mean task scores replaced the usual individual criterion scores, and quantitative task index values were used as predictor scores. This adaptation was tested using data from published studies on tracking. Significant multiple correlations using task indices were found for criterion data obtained during early stages of practice. This result supported the contention that a prescriptive method must include training as well as task indices in order to account for advanced levels of proficiency. A combination of task and training indices did predict later performance.

More generally, the results support the soundness of the task characteristic approach underlying the broader program. A major conclusion was that further development of the quantitative task-analytic methodology is warranted and would be fruitful.

FOREWORD

INTRODUCTION

The prediction of human performance is highly task specific. Human information processing requirements, stress and overloading, differ from task to task. Although some of the characteristics of the task which create such differences are known, quantitative indices of task characteristics for use in predicting these differences in human performance are generally lacking, especially with respect to the joint influence of several task characteristics as found in complex military tasks. Without quantitative information relating human performance and task characteristics, such things as the instructor's performance level and the trainee's learning rate in a new trainer are difficult to estimate until that trainer is operative.

PURPOSE

The objective of this research project is to develop quantitative indices of the characteristics of instructors' and trainees' tasks so that the effectiveness of a given amount and type of training on a given task can be predicted. The results of this research should lead to greater accuracy in establishing the human performance requirements in a training system, greater accuracy in human factors design recommendations, and improved instructor station design.

In the first phase of this research project--which this technical report describes--the objective was to develop a method for quantifying the tasks involved in training device situations, utilizing indices and techniques previously developed and reported in the literature.

ACCOMPLISHMENTS

The objective of the first phase was accomplished very successfully. The initial set of quantitative indices was tested for its feasibility in describing the trainee tasks on three sonar operator training devices. Feasibility was demonstrated.

Further, the feasibility of using quantitative task characteristic indices to predict performance was tested by describing the characteristics of tracking tasks appearing in the experimental literature and predicting tracking performance.

The successes obtained in this first phase reinforce the decision to continue the attempt to develop quantitative profiles of training device tasks and to predict performance from such profiles.

PLANS

The planned next step is to apply quantitative indices to the trainee and instructor tasks of actual training device situations and to predict performance in those situations.

IMPLICATIONS

It is believed that the development and validation of this type of methodology will make it possible to answer such questions as the following:

(a) What is the relative difficulty of operation of alternate equipment design?

(b) How long will it take the instructor or trainee to learn the task?

(c) How well is the task capable of being performed?

(d) What is the optimal trainee to instructor ratio?

(e) What is the effectiveness of a given amount and type of training on a given task?

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ACKNOWLEDGMENTS

The focus of this project was on the "real world", a setting in which the best laid research plans are often moderated by reality. The ability of this project to meet and overcome the problems associated with research "in the field" was due in large measure to the support of the Project Monitor, Dr. Gene S. Micheli. The project staff wishes, therefore, to thank Dr. Micheli for his cooperation and able assistance, factors which contributed directly to the success of this project.

Research conducted during the course of "site visits" can often be a frustrating affair. Site-visits made during the present study, however, were highly rewarding. This was primarily due to the interest and unusually able assistance provided by the officers and enlisted personnel of the U. S. Navy Fleet Sonar School, Key West, Florida. Individuals too numerous to mention gave unstintingly of their time and energy. The project staff would like to extend special thanks to Capt. Sanders, Commanding Officer; Cmdr. Kilborn, Executive Officer; Lt. Cmdr. Jones; Lt. Tennant; Chief Petty Officer Morton; and Petty Officers Smith, Staib, and McRae.

The authors, of course, did not do all of the work reflected by this report. We would like to take this opportunity, therefore, to acknowledge the contributions of other project members. Thanks are extended to Dr. William J. Baker of AIR who developed much of the rationale underlying the predictive model used in this study. Thanks are also extended to Miss Susan Emery of AIR. Susan made valuable contributions throughout the course of the project. Last, but by no means least, thanks are extended to Mrs. Lily Griner, project secretary, for her patience and able assistance.

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I.0 INTRODUCTION

One of the most difficult and complex problems [illegible] individuals responsible for military training [illegible] the development of effective training systems. Accepted as inputs to such systems are students who lack specific knowledge or skills. As the students progress through the system, they are exposed to a variety of new situations, and through practice are afforded an opportunity to develop and refine new skills. In military training systems the bulk of this exposure is often provided by sophisticated training devices which incorporate conditions intended to facilitate, guide, and reinforce the learning experience. The objective in supplying such exposure is to output graduates who possess new knowledge and skills, and who can transfer these assets to an operational situation. The effectiveness of this process, and of the system components which underlie it, depends largely upon the speed of skill acquisition, and the degree to which these skills transfer to the operational setting.

While the goal in designing military training devices is always one of maximizing effectiveness, any given device may fall short of this mark. Two devices having the same training objectives can differ markedly in terms of the training time required or the type and amount of transfer achieved. Were a choice available between prototypes of these devices, only one might be selected for development. Because of the costs involved in current system design and implementation, however, one cannot afford to develop competing devices and empirically determine which is more effective. In other words, a "wait-and-see" attitude about the effectiveness of training is impractical.

The basic issue, therefore, is how to plan for, design, and develop a training device which will prove to be effective for a particular set of training objectives. Given the requirement for training, how can one forecast the type of training device which should be employed? How can one specify the manner in which the device should be designed and utilized? In short, what steps can be taken to insure, insofar as possible, the rapid acquisition of skills and their positive transfer to the operational setting?

In the 25 years since World War II, few other training problems have received as much attention. The problem has come under repeated attack and has been approached from a number of different theoretical positions. Various methods have been conceived to help determine what should be trained and how training should be accomplished. Many of these approaches have shared the assumption that operational tasks possess certain critical characteristics which have specific implications for the design and utilization of training devices. It was hoped that this information, together with estimates of cost, would lead to training decisions which insured maximum returns for each training dollar invested. In spite of several efforts in this direction, however, the problem of prescribing the design of a training device, or of predicting its effectiveness, remains unresolved.

1.1 Methods for Increasing Training Effectiveness

Historically, gross inadequacies in the design of training devices were often eliminated on the basis of shrewd guesswork. In the earliest approach to the prescriptive-predictive issue, design decisions were made by subject-matter specialists who drew on experience and common sense to solve training design problems. As a result they often were able to make fairly sound decisions about the design of training aids and equipment, student and instructor stations, and other aspects of the training situation which might facilitate the learning experience. However, these early practitioners were artisans. Because of their experience, they were able to translate certain types of information about the job to be performed into requirements for training. As is true of all artists, however, they differed in terms of their conceptualization of and the approach to the training problems which faced them. As a result, some were highly successful in making sound training decisions. Others were not. Furthermore, because of the informal and implicit nature of their methods, it was difficult to train others in their use. But the major disadvantage of this approach lay in the difficulty of evaluating the proposed training solution prior to its adoption. Predictions as to the effectiveness of training were scarcely better than opinion. As has been cogently pointed out elsewhere (Chenzoff & Folley, 1965):

> "One can never know, about any training program so devised, whether all of the important aspects of the man-machine system have been considered, whether training has been prescribed for those system segments which have the greatest relationship to system effectiveness, nor whether the training program is particularly well suited to teaching the specific skills and knowledges which must be conveyed. It is extremely difficult to assess, before the fact, whether each training dollar will be well spent" (p. 2).

Because of the difficulties inherent in these individualistic methods, attention was focused upon the development of more formal and programmatic approaches to the solution of training device design and utilization problems. Techniques were conceived and developed to help determine what should be trained and to provide very general guidelines as to how training should be accomplished.

The results of these efforts were a number of job descriptive and task analytic procedures. Using these approaches it became possible to describe jobs in terms of their major task components, and then to describe these components in terms of underlying task elements and activities. Description proceeded systematically through several levels.

At each successive level the information which was extracted became more detailed. Additional techniques were employed to either expand upon or integrate portions of this information. The earliest of these procedures (e.g., Miller, 1953; Miller & Van Cott, 1955) were designed to help specify those aspects of an operational task which should be considered as basic items of content in a training program. More recent efforts (e.g., Chenzoff & Folley, 1965), while maintaining an interest in specifying the appropriate content of training, have also attempted to prescribe the type and amount of training which should be given.

Concurrent with these activities, other investigators were attempting to develop task classification systems having implications for training. These taxonomists shared the belief that basically different types of tasks did indeed exist. Given this premise, a logical step was to collect, sort, and catalogue tasks, casting them into their appropriate classes or families. Taxonomists who developed their structures to deal with training problems made an additional assumption. For each identifiable class of tasks there might exist an unique set of training procedures which would prove to be most effective. As a consequence of this thinking there have been several attempts to classify tasks and to specify for each class those training techniques which seem most appropriate (e.g., Willis & Peterson, 1961; Stolurow, 1964; Miller, 1966).

Many of the analytic and taxonomic methodologies developed to date have had their own particular shortcomings. Most, however, have had one weakness in common. They have provided for the description of tasks in behavioral or functional terms (e.g., the behavioral taxonomy of Berliner, Angell, & Shearer, 1964; the functional descriptors employed by Gagne, 1962 and Miller, 1966). These terms have been found difficult to apply unambiguously. They have referred primarily to the qualitative aspects of an operator's overt and covert behaviors.

Considered collectively, these qualitative approaches have helped determine those aspects of the operational situation which should be considered as basic items of content in the training program. To a much more limited extent, they have even provided general guidelines about how training might best be accomplished. They have not been particularly successful, however, in establishing specific training device design requirements. As pointed out by Smith (1965) in an interesting comparative study, it has been difficult to translate the behavioral analyses into rigorous training technique or hardware specifications. Because of their qualitative nature, it has not been possible to use these methods to predict the effectiveness of different types or amounts of training.

1.2 Research Related to Training Effectiveness

The problem of maximizing training device effectiveness is two-fold: 1) to predict, as early as possible in the design process, how effective training will be; or 2) to specify that design, which if carried through, will prove effective. In either case, the problem is overwhelmingly complex, since in any training situation there are several major classes of variables which may interact to determine the rate of trainee skill acquisition or even the level of instructor proficiency. These components are the trainees who are selected, the characteristics of the tasks embodied in the training device, and the techniques employed to effect training.

In mentioning these particular components an important point is to be made. If methods for predicting the effectiveness of a given type and amount of training are to be developed, the complex interactions among these components must be investigated. Studies of this type, however, have been relatively scarce. While the prediction of learning rate or performance level has intrigued behavioral scientists for a number of years, the tendency has been to focus on separate aspects of the problem. These divergent interests have been reflected in the growth of three rather separate areas of research. These areas have included individual differences, principles of learning, and human engineering.

The first of these areas has been aimed at determining student-related attributes which may underlie individual differences in training. The value of this research lies in the promise it holds for using such student attributes as a basis for student selection. The rationale for this selection is that the most effective training can be provided to those students who possess attributes related to rapid acquisition of certain skills or to high levels of proficiency on certain types of tasks.

A number of studies, for example, have indicated that the abilities derived through experimental-correlational research are involved in varying degrees and combinations in learning to perform a variety of tasks. Among others, Fleishman and Fruchter (1960) and Parker and Fleishman (1960, 1961) have applied this knowledge while providing training on a variety of complex tasks. Few of these studies, however, have attempted to map the relationships between different student attributes and different tasks or the stimulus and response properties of such tasks. Until this research is undertaken on a large scale, it will be difficult to predict which students will gain most from practice on different types of tasks. Lacking this information it is difficult to determine how much device effectiveness can be increased through personnel selection.

The second relevant area has focused on the development of principles of learning and the translation of these principles into sound training practices. These have included, for example, the work of Bilodeau and Bilodeau (1961) on feedback, the distribution of practice studies by Kientzle (1946) and Jensen (1961), Cofer and Appley's (1964) work on motivation, and Caro's analysis (1969) of adaptive training.

In spite of the investigation of a large number of such variables, however, it has been difficult to translate this body of research into the design of improved training devices.

This difficulty has arisen for three reasons. First, few experiments have been conducted to explore the interactions among different training variables. In the absence of this type of research it has been difficult to evaluate device effectiveness in terms of trade-offs among training variables. Second, there have been few attempts to establish the interactions between selected training variables and student attributes or abilities. Third, with the exception of a few studies (e.g., Tallmadge and Shearer, 1970) the interactions between selected training variables and the types of tasks being trained have not been thoroughly explored. More of this latter type of research is needed if training techniques are to be tailored to the tasks incorporated within a particular training device.

The third relevant area of research has focused on stimulus and response aspects of a task, which if varied, may exert an effect upon operator performance. The research in this area has been voluminous. It has led to the generation of a number of handbooks prescribing the design of most aspects of the man-machine interface (e.g., the Human Engineering Guide to Equipment Design, 1963; the Handbook of Human Engineering Data, 1960). While of immense value in its present form, this research must be extended. More studies of the type conducted by Chapanis and Gropper (1968) are required on the interaction between operator characteristics and display-control relationships. Similarly, more information is needed of the type supplied by Fowler, Williams, Fowler, and Young (1968) on differert operator panel lay-outs and rates of learning.

In order to cope successfully with the prescriptive-predictive issue, human-engineering research is especially needed on the interaction between trainee and instructor. At his station, the trainee attends to inputs from specific displays, processes them in a prescribed manner, and attempts to take appropriate control actions. The instructor, at his own station, deals with different controls and displays, and performs distinctly different operations. To some extent, however, each station's output is a function of inputs from the other station. Because of this dependency, a training device is actually a closed-loop system. Therefore, device effectiveness will depend upon how well both participants perform their respective tasks. Consequently, design prescriptions must simultaneously relate to both stations, and predictions of training effectiveness must consider their joint influence.

In summary, the three areas of research described above indicate that training effectiveness is determined by an interaction among components of the training system. Study of this interaction may eventually provide the design engineer with information about the personnel, technique, and design trade-offs which are so crucial to development of an effective training device. Until the relationships among these components are thoroughly understood, the problem of designing an effective training device, before the fact, will remain unresolved.

1.3 Statement of the Problem

The present study was conducted as part of a larger program of research. The goal of this program was development of a new approach to the problem of specifying the design of a training device or of predicting its effectiveness. The approach under consideration was one of quantitative task analysis.

As the first step in this program the present study had three objectives. The first objective was to compile an initial set of quantitative indices relating to selected characteristics of various man-machine tasks. The second objective was to determine whether the obtained indices could be used to describe a sample of trainee tasks and to differentiate among them. The third objective was to develop a predictive methodology based upon the task indices and to assess its potential utility.

2.0 METHOD

Two methods were employed in the present study. In the first procedure quantitative task indices were compiled and applied to trainee tasks found in surveillance-system training devices. The purpose of this procedure was to assess the feasibility of quantitatively describing a variety of complex man-machine tasks. In the second procedure a multiple-regression model was developed and applied to a sample of tracking tasks described in the literature. This procedure was designed to provide preliminary estimates of the predictive power of selected task indices. The major steps in both approaches are described below.

2.1 Task Analysis

Four major steps comprised the task analysis procedure. First, a sample of training devices was selected upon which to base the eventual quantitative task analysis. Second, the trainee tasks associated with the selected devices were analyzed to identify major sub-tasks believed to cut across a number of training devices. Third, quantitative indices were selected or developed relating to characteristics of the major trainee sub-tasks which had been selected for study. Fourth, task analysis data were collected in the field and used to derive values for both generic and specific sets of quantitative indices.

2.1.1 Selection of Training Devices

A large portion of the spectrum of Navy training devices was reviewed in order to identify those instances in which training equipments rather than training aids provided the basis for instruction. The former devices (e.g., trainers and simulators) were chosen for investigation because: 1) they contained trainee and instructor tasks which were reasonably formalized and invariant with respect to the equipment and procedures used; and 2) they permitted relatively sharp boundaries to be drawn between the trainee and instructor tasks. Both of these features were desirable for development and application of quantitative indices.

On the basis of the review approximately 165 different trainers or simulators were identified. These equipments differed markedly, however, in terms of the basic content of training (e.g., vehicle control, fire control, navigation, etc.) and level of training (e.g., orientation, familiarization, skill, etc.). A decision was required, therefore, whether to sample across these many different types of trainers or to focus on a more homogeneous sub-set of devices. The latter approach was finally adopted because it was felt that focus on a specific sub-set of devices would provide a better test of the overall methodology. If quantitative indices could not be applied to a specific class of trainers, then there would be little hope of doing so across many different types of devices.

The 165 devices previously identified were re-evaluated with respect to the content of training, and were organized into relatively homogeneous families. Nine clusters emerged which included the following:

a) operational flight trainers
b) cockpit procedures trainers
c) weapon system trainers
d) antisubmarine warfare team trainers
e) airborne electronic warfare trainers
f) electronic countermeasures trainers
g) radar trainers
h) sonar trainers
i) miscellaneous trainers.

Two sets of criteria were applied to each group of devices. One set was designed to identify groups of devices which appeared best suited to development of quantitative indices. The second set was used to specify which groups might be most readily evaluated in an anticipated regression analysis.

In light of the criteria for development of indices and for evaluation of the descriptive system, radar, sonar, and electronic countermeasures trainers were selected. These devices belonged to the same general family in the sense that they provided training for the operators of Navy sensor-based or surveillance systems. For purposes of the present study attention was focused on active, surface-sonar trainers. In spite of this restriction, the intention was to generate indices which would also provide for the quantitative description of other devices within the surveillance family.

2.1.2 Identification of Trainee Sub-Tasks

Having identified surveillance system training devices as the family of interest, the trainee tasks associated with these devices were analyzed in detail. The analysis was conducted for two reasons. First, information was required on the major sub-tasks performed by trainees. Second, information was desired about those features of the sub-tasks which might provide a basis for generation of descriptive indices.

The decision to provide description at the sub-task level was predicated on two assumptions. First, although surveillance trainers might differ in the content of training, they nevertheless would share certain basic sub-tasks. Second, only at the sub-task level could criterion performance measures be readily identified. The availability of such measures was essential if the quantitative indices were eventually to be used in the prediction of learning rates or proficiency levels.

Ten devices were evaluated during site visits to the Fleet Sonar School, Key West, Florida, and the Naval Air Station, Glynco, Georgia. Based upon this analysis and upon examination of a number of utilization manuals, four, major, trainee sub-tasks were identified which cut across surveillance training devices. The first sub-task was procedural in nature and involved receiver turn-on, set-up, and/or calibration in preparation for search activities. The second sub-task, involving monitoring of the receiver, resulted in signal detection or target acquisition. In the third sub-task, displayed signals were analyzed to permit target identification and classification. The fourth sub-task involved tracking of the target in order to provide continuous or discrete information about target range and bearing. All four sub-tasks were readily identifiable in the active, surface-sonar devices with which the study was primarily concerned.

2.1.3 Selection of Quantitative Indices

In selecting and developing a set of quantitative indices there was an embarassment of riches. Once compilation of the list of descriptors began it was all but impossible to stop. To combat this excess a line had to be drawn somewhere. Consequently, quantitative indices were sought which related only to critical characteristics of each of the trainee sub-tasks identified above. Critical characteristics were those which, if manipulated, could be hypothesized to exert an appreciable effect upon rate of acquisition or level of proficiency.

Based upon a review of the literature and upon an examination of the four trainee sub-tasks of primary interest, two sets of indices were generated. The first set consisted of generic indices. Each index within this first set was applicable to all of the trainee sub-tasks as well as to the task of the instructor. The generic indices included: 1) task characteristic rating scales; 2) a display evaluative index; and 3) a variety of panel lay-out and task-type indices. The second set contained specific indices which were developed to provide for a more detailed description of each of the trainee sub-tasks. An index within this second set was specific in the sense that it would apply to at least one, but not to all, of the trainee sub-tasks.

2.1.5.1 Rating Scales - A total of 15 task characteristic rating scales was selected from a larger set of 19 scales originally developed during the course of an AIR taxonomy project (Fleishman, Teichner, and Stephenson, 1970). The scales were specifically designed to describe tasks per se, independent of two other major components of performance, the operator and the task environment. Development of the scales proceeded from a definition which structured the term "task" into several components: the goal, responses, procedures, stimuli and stimulus-response relationships. Several rating scales were developed for each of these components, and small-scale studies were performed to assess inter-judge reliabilities. A complete discussion of the task characteristic approach is given in a report by Farina and Wheaton (in press).

For purposes of the present study the rating scales were reassessed with the surveillance sub-tasks in mind. Where possible, a change was made from rating the magnitude of a characteristic (on a seven-point scale) to actually counting the quantity involved. For example, rather than rating the number of responses required to produce an output unit, such responses were counted. Consequently, the resulting instrument was a mixture of rated and counted characteristics.

Although all of the scales provided quantitative information, a few of them were actually based on qualitative distinctions. In these cases the different qualitative states were assigned arbitrary values on a nominal scale. Definitions for each task characteristic and the associated rating scales are presented in Appendix A. The task characteristic indices employed in the present study included the following:

a) Number of output units (UNIT)

b) Duration (DURA)

c) Number of elements per output unit (ELEM)

d) Work load (LOAD)

e) Precision of responses (PREC)

f) Simultaneity of responses (SIMR)

g) Number of responses (NO.R)

h) Rapidness of feedback (FEED)

i) Response rate (RATE)

j) Tutorial dependency (TUDE)

k) Natural dependency (NADE)

l) Operator control of the response (OCOP)

m) Variability of stimulus location (VARS)

2.1.3.2 Display Evaluative Index - Over the last decade a number of attempts have been made to translate human engineering principles into quantitative measures. Among these has been Siegel's Display Evaluative Index (DEI).

The DEI is a measure of the effectiveness with which information flows from displays via the operator to corresponding controls. The index yields a dimensionless number which represents a figure of merit for the total configuration of displays and controls being evaluated. It was originally derived from a set of assumptions about what constitutes efficient information transfer in display-control systems. For example, all else being equal, that system is best which has the greatest directness between the information transmitter and the corresponding controls, efficiency being reduced where the operator has to transform information before taking action.

The potential value of the index has been demonstrated by its wide applicability. Surveillance, fire-control, and even communications systems have been quantified with it (e.g., Siegel, Miehle, & Federman, 1962a; Siegel & Lederman, 1967). Moreover, the index has been partially validated, i.e., against judgements by human engineering experts (Siegel, Miehle, & Federman, 1962a, 1963). It was decided, therefore, to include the DEI in the current project with a view toward extending its prescriptive-predictive potential to the design of training devices.

2.1.3.3 Panel Lay-Out and Task-Type Indices - The indices of Fowler, et al. (1968) are designed to provide description of two different aspects of a man-machine task. One set of indices is used to measure, in percentage, the extent to which general human engineering principles have been applied to the arrangement of controls and displays on a console. The second set relates to the degree, again expressed as a percentage, to which different operations or "task types" are embodied in a particular operator console. These indices can vary independently of the DEI which does not address itself to panel arrangements or types of panel operations.

In the present study one lay-out index was used, the "total sequencing score". Four "task-type" indices were employed including the following: 1) an "alternative action sub-score"; 2) a "breaks in operation sequence sub-score"; 3) a "frequency-of-use score"; and 4) an "importance-of-use score". In addition to these major indices, certain measures involved in their calculation were also used as descriptors. These included: 1) total link value; 2) number of controls and displays; and 3) total number of response actions.

2.1.3.4 Miscellaneous Generic Indices - To round out the initial set of generic indices, seven additional measures were employed. Response actions were broken down into the following categories: 1) number of non-normal repertoire responses (Folley, 1964); 2) number of control activation responses; 3) number of feedback responses; 4) number of information acquisition responses; and 5) number of instructor initialized responses

(Mackie & Harabedian, 1964). Two additional indices were the number of redundant information sources processed simultaneously (Mirabella, 1967), and the time permitted for sub-task completion.

With the inclusion of the seven indices just described, the generic set consisted of 29 separate measures. This set was deemed acceptable for initial work in terms of both the number and variety of descriptors which were available.

2.1.3.5 Specific Indices - In addition to generic indices, which cut across both training devices and trainee sub-tasks, an additional set was selected. Indices within this set were specific to surveillance trainers and to certain sub-tasks within those trainers. The items were selected because they appeared to have implications for device design decisions and because they appeared to be directly translatable into trainer design specifications.

The 15 specific indices developed for use in the present study included the following:

a) signal persistency expressed as the ratio of phosphor persistence to the ping interval;
b) range in signal to noise ratios;
c) bearing control-display ratio;
d) range control-display ratio;
e) number of tracking dimensions;
f) variation in target range;
g) variation in target speed;
h) bearing error tolerance;
i) range error tolerance;
j) number of cues available for classification;
k) number of classification cues applied simultaneously;
l) number of false targets used;

m) target to non-target ratio during training;

n) number of contacts per minute; and

o) sequencing of problem scenarios.

Of interest but not directly relevant to the description of trainee tasks were 10 additional indices. Most of these were binary descriptors and related to the use of different training techniques. These included statements, for example, about the use of training tapes, adaptive techniques, part-task training, problem freeze techniques, etc. Altogether, therefore, 29 generic indices, 15 specific indices, and 10 training technique descriptors were assembled for later use.

2.1.4 Application of Indices

The general and specific indices discussed above were applied to task-analytic data collected on three sonar operator training devices in use at the Fleet Sonar School, Key West Naval Base, Florida. The three trainers examined were: the 14B10, representing the AN/AQS-13 helicopter stack, the AN/SQS-26CX, and the 14E3, representing the AN/SQS-4 sonar. The "26" and the "4" are destroyer systems. All three systems have at least some capability for detection, localization and classification of submerged contacts. Instructors, regularly assigned to these trainers, went through the operation of each surveillance system in the sequence taught to novice operators. Considerable care was taken both by the instructors and by the observers to maintain a training rather than an operational set.

Procedures for equipment set-up, detection, localization, and classification were included in each demonstration. For each of these sub-tasks the instructor indicated and described every display and control used and their sequence of use. This information was recorded on three forms: 1) an activity table describing the actions performed; 2) an equipment function table describing the displays and controls; and 3) an operational sequence diagram. There was some deliberate redundancy among the data forms. These respective forms are illustrated for the [illegible] localization task in Tables 1 and 2, and in Figure 1. (Operations flow charts for the remaining tasks and devices are presented in Appendix B.)

Table 1 shows main line actions on the left and contingency actions on the right. Table 2 describes the displays and controls corresponding to each line of action in Table 1. Table 2 includes response number, equipment reference number, designation of equipment as a control (C), display (D), or a combination of both (B). Also included are equipment nomenclature and number of hardware units (number of discrete values which can be read out of a display or entered into a control). The "In response repertoire" column indicates whether the specific action required is part of the trainee's normal repertoire or whether it represents a skill to be acquired. The "Feedback" column represents responses in which the adequacy of a preceding response is confirmed. The "Importance" column indicates the criticality of an erroneous response. A "1" rating indicates that the training mission would be inhibited but the error is correctable. A "2" rating indicates that the mission would fail but the error is correctable. A "3" rating indicates maximum criticality, i.e., a wrong response results in damage to the equipment. The "Control by instructor" column indicates instances in which the instructor manipulates a control for the trainee or tells the trainee to enter a specific value into a control.

Figure 1 represents an integration of information contained in Tables 1 and 2. The sequence of actions required in the localization sub-task is shown graphically from left to right. Squares denote actions involving use of a display while circles connote actions involving controls. The main sequence of responses is represented by a solid line between controls and displays while contingency response sequences are indicated by broken lines. Controls and displays are arbitrarily numbered, starting from the left, to indicate when they are used in the sequence of responses.

Table 1

Activity Table for 14B10 Localization Sub-Task

Resp. #	Response Description	Contingency Response #	Contingency Response Description
1	Monitors target on display #22		
2	Rotates control #10 and #23 to align cursor with target		
3	Monitors position of cursor relative to target on display #22		
4	Reads bearing data from display #20		
5	Reads range data from display #20a		
6	Depresses foot pedal (#30) to call pilot		
7	Receives go ahead from pilot over earphones (#29)		
8	Uses microphone (#31) to report range and bearing		
9	Receives bearing "clear" or "foul" information from #29		
		9.1.a	If bearing is "foul" the search sub-task is reinitiated by rotating control #6.
10	Monitors #22 for target motion		
11	Rotates control #10 and #23 to keep cursor on target		
12	Monitors position of cursor relative to target on display #22		
13	Check #20a for range relative to previous range setting		
		13.1.a	If range is increasing or decreasing, manipulates #11 to select a new range scale

Table 1 (Continued)

Resp. #	Response Description	Contingency Response #	Contingency Response Description
		13.1.b	Verifies change in range on #22
		13.1.c	Verifies change in range on #20a
14	Monitors #29 for target		
		14.1a	If audio return is lost, checks target position on #22
		14.1b	Activates control #8 to reacquire audio
		14.1c	Monitors #29 for re-appearance of target
15	Monitors #22 for target		
16	Rotates #19 and #23 to track target		
17	Monitors #22 for target		

Table 2

Equipment Function Table for 14E10 Location Sub-Task

Resp. #	Equip. #	C,D,B	Equip. Nomenclature	Hardware # Units	In Response Repertoire?	Feed-back?	Importance	Controlled by Instructor?
1	22	D	PPI	-	Y	Y	1	N
2	10,23	C	Bearing and Range Wheels	-	N	N	1	N
3	22	D	PPI	-	Y	Y	1	N
4	20	D	Bearing Indicator	72	Y	N	1	N
5	20a	D	Range Indicator	2000	Y	N	1	N
6	30	C	Foot-Pedal	2	Y	N	1	N
7	29	D	Earphones	-	Y	Y	1	N
8	31	C	Microphone	-	Y	N	1	N
9	29	D	Earphones	-	Y	Y	1	N
9.1.a	6	C	Listen Sector Switch	2	Y	N	1	N
10	22	D	PPI	-	Y	N	1	N
11	20,23	C	Bearing and Range Wheels	-	N	N	1	N
12	22	D	PPI	-	Y	Y		
13	20a	D	Range Indicator	2000	Y	N	1	N
13.1.a	11	C	Range K Yards Select Switch	5	Y	N	1	N
13.1.b	22	D	PPI	-	Y	Y	1	N
13.1.c	20a	D	Range Indicator	2000	Y	Y	1	N
14	29	D	Earphones	-	Y	N	1	N

Table 2 (Continued)

Resp. #	Equip. #	C,D,B	Equip. Nomenclature	Hardware & Units	In Response Repertoire?	Feed-back?	Import-ance	Controlled by Instructor?
14.1.a	22	D	PPI	-	Y	N	1	N
14.1.b	8	C	Reception Direction Switch	S	Y	N	1	N
14.1.c	29	D	Earphones	-	Y	Y	1	N
15	22	D	PPI	-	Y	N	1	N
16	10,23	C	Bearing & Range Wheels	-	N	N	1	N
17	22	D	PPI	-	Y	Y	1	N

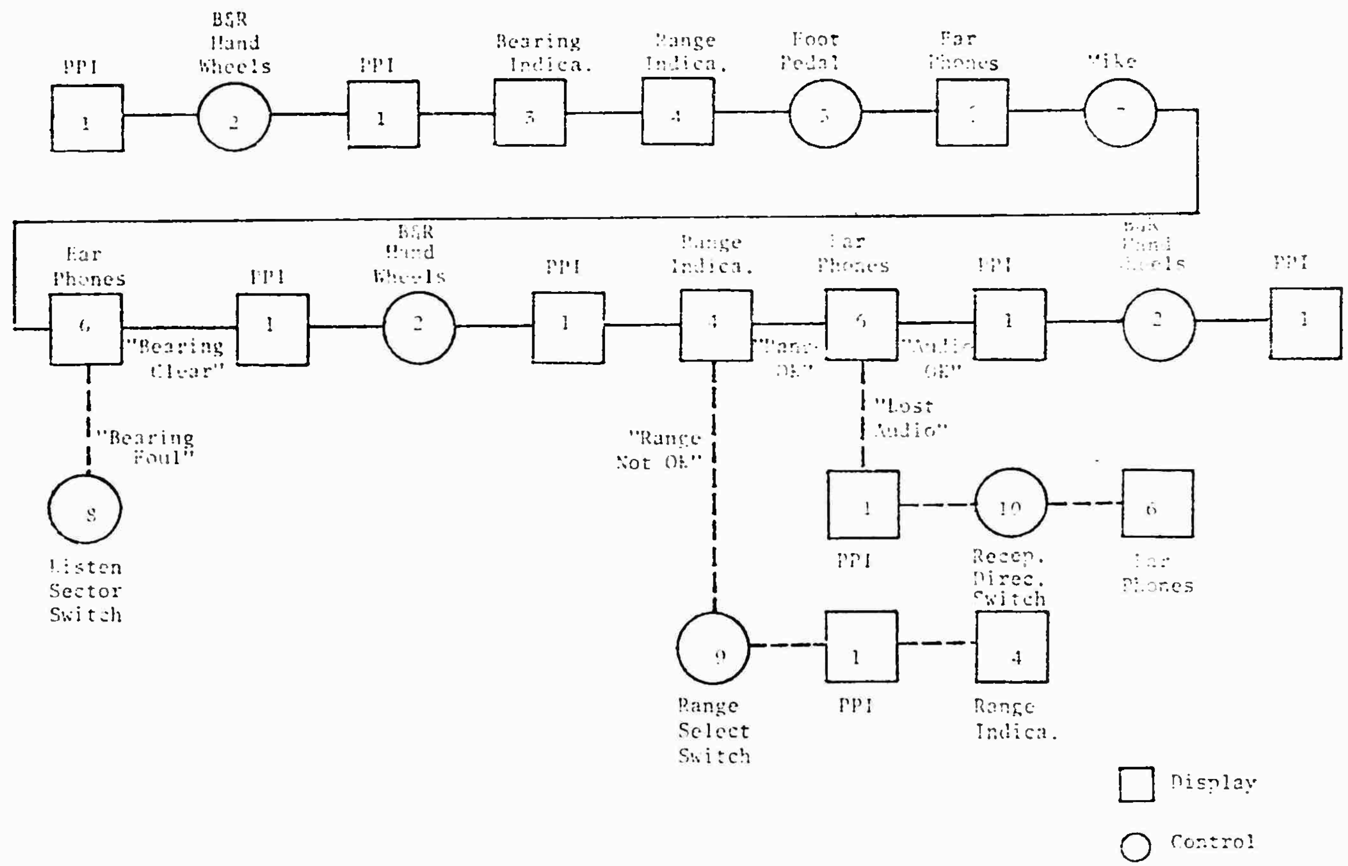


Figure 1. [illegible] Localization Sub-Task Operations Flow Chart

2.1.4.1 Display Evaluative Index (DEI). [illegible] illustrated in Tables 1 and 2, and Figure 1, [illegible]. The DEI formula is (Siegel, Miehle, & Federman, [illegible]):

$$\frac{(n + m)_u \left[\exp(-1/4\ \Sigma W/N)\right]}{(1 + \Sigma M)\sqrt{Q(n + m)_t\ (N + n_o)}}\text{, where}$$

n = number of indicators (i.e., displays);

m = number of controls;

N = the number of forward links, i.e., dotted links from controls to displays are not counted (Figure 2);

$(n + m)_u$ = number of indicators and controls actually used on the console during a particular sub-task;

$(n + m)_t$ = total number of indicators and controls on the console;

ΣW = sum of weights applied to indicator-control links and to rectangles representing operator data processing; weighting procedures are defined in Siegel, et al. ([illegible]);

$\Sigma/M/$ = sum of absolute values of mismatches between indicator and control resolution;

Q = total number of display and control elements for used controls and displays (e.g. in the 14F10, localization is accomplished by manipulating separate bearing and [illegible] wheels, which can be thought of as two elements of a single control);

n_o = number of boxes and triangles representing processes that intervene between the reading of indicators and the manipulation of controls, where triangles are used to represent "and" gates and "or" gates.

Following the procedure outlined in Siegel, et al. (1962[illegible]) task analytic data for each sub-task of each training device were reduced to information transfer charts. From the charts, tables of links were established. Then the appropriate formula sums were obtained and the DEIs calculated. These procedures are illustrated in Figure [illegible] and in Tables 3 and 4. (Link charts are presented for the remaining training devices in Appendix C.)

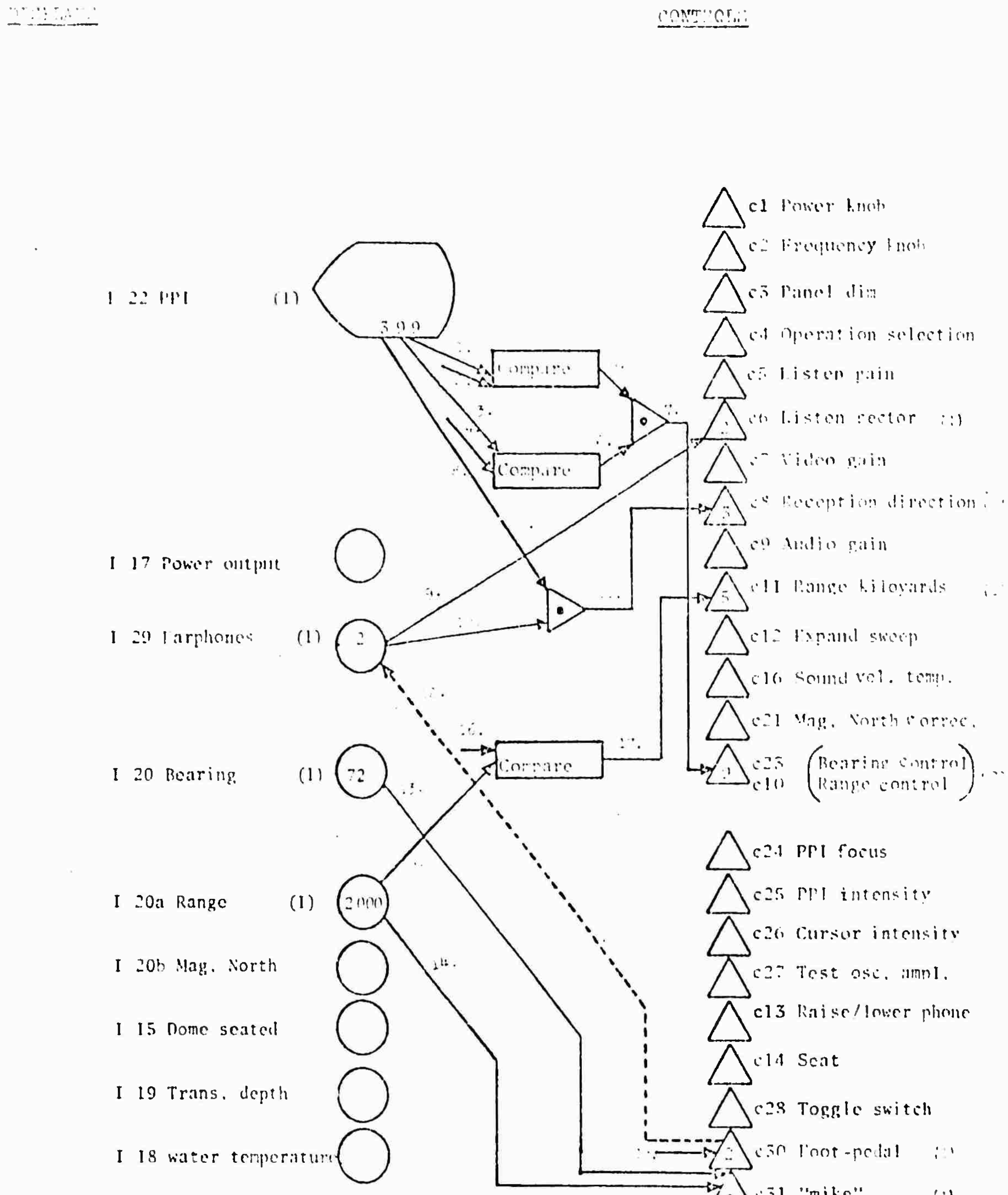


Figure 2. 1/E10 Localization Sub-Task Link Chart

Figure 2 shows displays on the left, controls on the right and intervening process symbols in the center. Connecting these symbols are links which indicate the direction of data flow. Solid lines extending from display or processing symbols are information links. These imply actions based upon display reading or data processing by the operator. The short solid lines which terminate on a processing or control symbol are instructional links. These imply actions taken on the basis of instructions or stored information. The dotted lines extending from controls to displays are corroborative (i.e., feedback) links. These imply that the operator is checking the effects of some control action.

The number within the display and control symbols indicates the number of different values which can be read or manipulated. For example, I22 is a PPI which, for purposes of adjusting the bearing and range wheels, takes on a total of nine values, i.e., the cursor can be short of the target, beyond the target, leading the target, lagging the target, on the target, leading the target and short, leading the target and long, lagging the target and short, or lagging the target and long. These nine states are associated with the links going to the upper two "compare" boxes. However, for purposes of setting the reception direction control, the PPI takes on three values, i.e., the search sector will either coincide with the target sector, lead it or lag it. These three states are associated with the link going to the "and" gate.

The number of elements per display or control is indicated in brackets next to the control or display symbol. The intervening symbols include three compare boxes and two "and" gates. The upper two rectangles for example, designate that the trainee compares cursor position in bearing and range with target position. The "and" gate designates that the trainee combines video and audio information to set the "reception direction" switch.

Table 3

DEI Link Table for the 14E10

Localization Sub-Task

Link No.	Link Type	Display Info. No. States	Display Info. No. Digits	Control Info. No. States	Control Info. No. Digits	MisMatch $\lvert M_i \rvert$	Link Weight (Wt)
1	INFO	9	.95				2.0
2	INST	9	.95				2.0
3	INFO	9	.95				2.0
4	INST	9	.95				2.0
5	INFO	3	.48				1.0
6	INFO	3	.48				1.0
7	INFO		.96[1]	9	.96	.00	0.0
8	INFO	3	.48				1.0
9	INFO	2	.30	2	.30		1.0
10	INFO	2	.30				0.0
11	INFO		.78[2]		.48	.30	0.0
12	CORROB	2	.30				0.5
13	INFO	72	1.86	72	1.86		2.0
14	INFO	2000	3.48	2000	3.48		2.0
15	INFO	2000	3.48				2.0
16	INST	2000	3.48				2.0
17	INFO	3	.48	5	.70	.22	1.0
18	INST	2	.30				1.0

$\Sigma \lvert M_i \rvert = .52$

$\Sigma W_i = 34.5$ (Each box receives a link weight of 4)

1. Number of display digits for link 7 = number of display digits for link 5 plus link 6.

2. Number of display digits for link 11 = number of display digits for link 8 plus link 10.

Table 4

DEI Worksheet for the 14F10

Localization Sub-Task

1.	$(1 + \Sigma W_i)$	=	35.5	
2.	$(n + m)_u$	=	10.0	
3.	$(n + m)_t$	=	32.0	
4.	N	=	17.0	
5.	Q	=		11.0
6.	n_o			5.0
7.	$(Q + n_o)$	=		16.0
8.	$N(n + m)_t (Q+n_o)$	=		8,704.00
9.	$\sqrt{N(n + m)_t (Q+n_o)}$	=		93.30
10.	Sum $\lvert M_i \rvert$	=		.52
11.	1/4 Sum $\lvert M_i \rvert$	=		.13
12.	exp (-1/4 Sum)	=		.88

$$\mathrm{DEI} = \frac{(n + m)_u \left[\exp\left(-1/4 \text{ Sum} \lvert M_i \rvert\right)\right]}{(1 + \Sigma W_i) \left[\sqrt{N(n + m)_t \, (Q + n_o)}\right]} =$$

$$= \frac{(10)\ (.88)}{(35.5)\ (93.30)} = \frac{8.8}{3,312.2} = .0026568$$

Table 3 describes in detail the links shown in Figure 2. The description includes link type, number of values which can be read from the associated display and/or entered into the associated control, mismatch between those numbers in digits, i.e., absolute difference between number of display digits and control digits, and link weight. The appropriate WFI sums are indicated at the bottom of the page. Table 4 is a worksheet derived from Siegel, Miehle, and Federman (1962b).

2.1.4.2 Panel Lay-Out and Task-Type Indices - The task analysis data shown in Table 1 and 2 and in Figure 1 were used to obtain values for eight panel lay-out and task-type indices. Only general methods for deriving index values have been described in the present report. A thorough and detailed description of these procedures has been provided elsewhere (Fowler, et al., 1968).

Many of the indices developed by Fowler, et al. (1968) are based upon the concept of a link. A link is defined as the hand movement between two controls and the eye movement between two displays or between a display and a control. In Figure 1 links are shown between the displays and controls employed in the 14E10 localization sub-task. Links involved in the main sequence of actions are represented by solid lines. Those occurring in contingency sequences are represented by broken lines.

The first step in deriving many of the indices is to convert the information shown in Figure 1 into a Link Value Table (Table 5). Each link in Figure 1 is listed in coded form in column 1 of Table 5. The first number in the code refers to the display or control from which a given link leaves. The second number refers to the hardware component which the link then enters. In columns 2, 3, and 4 of Table 5, the following data are recorded for each link: 1) the number of times the link is used; 2) the relative percentage of use of a link leaving a given control or display; and 3) a link value which is the product of data

Table 5

Link Value Table for the 14E10 Localization Sub-Task

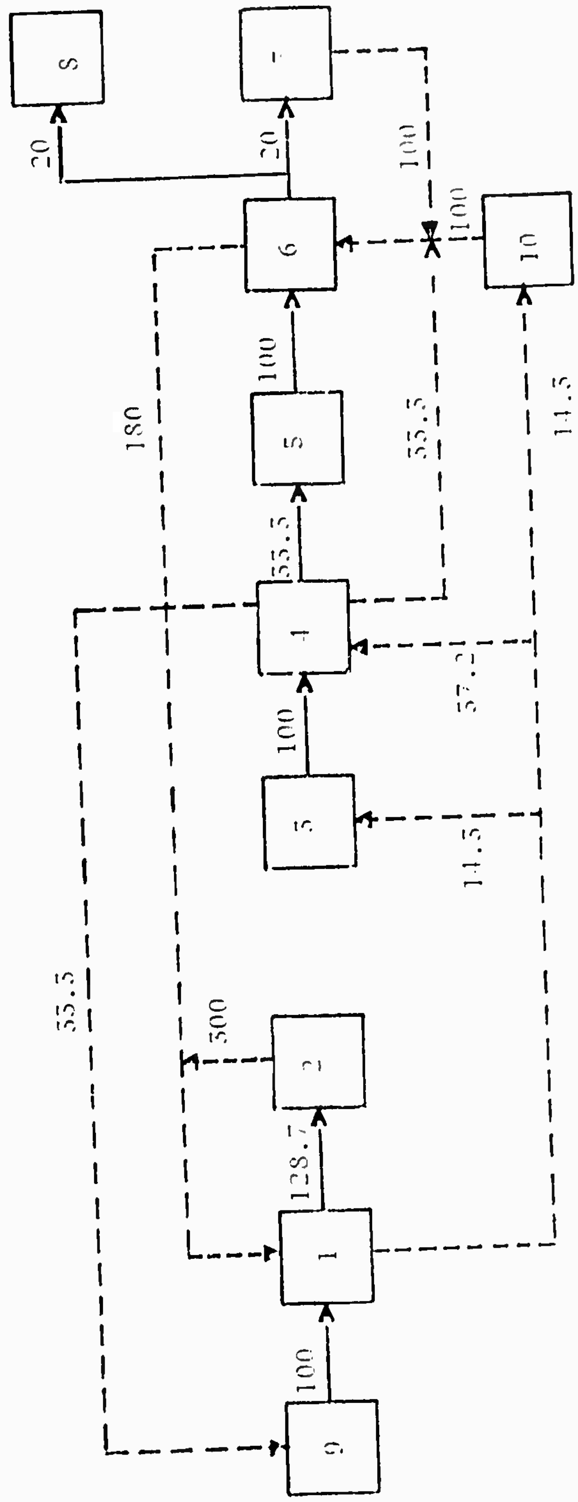
Links	No. Times Link Used	% Use	Link Value	Max. Link Value In & Out	Max. Link Value In Only	Max. Link Value Out Only	Remainder
1-2	3	42.9	128.7	X			
1-3	1	14.3	14.3		X		
1-4	2	28.6	57.2				X
1-10	1	14.3	14.3		X		
2-1	3	100	300	X			
3-4	1	100	100	X			
1-5	1	33.3	33.3		X		
4-6	1	33.3	33.3				X
4-9	1	33.3	33.3		X		
5-6	1	100	100			X	
6-7	1	20	20		X		
6-8	1	20	20		X		
6-1	3	60	180			X	
7-6	1	100	100			X	
9-1	1	100	100			X	
10-6	1	100	100			X	
			1334.4				

recorded in the second and third columns. In columns 5, 6, 7, and 8 of Table 5 check marks are entered to indicate whether each link value is: 1) the maximum value leaving a control and entering a display (Table 5, link 1-2); 2) the maximum value entering (Table 5, link 1-3); 3) the maximum value leaving (Table 5, link 5-6); or 4) none of the cases above (Table 5, link 1-4).

The information in Table 5 is used to generate a panel lay-out diagram in which controls and displays are oriented according to a sequencing principle/technique. Based upon this principle, displays and controls are arranged from left to right or top to bottom according to a series of rules described by Fowler, et al. (1968). A panel lay-out diagram for the 14E10 localization sub-task is shown in Figure 3. Solid lines indicate links which move from left to right in accordance with the sequencing principle. Broken lines indicate links which move left, directly up or down, or which move right but bypass one or more controls or displays. These latter links are in opposition to the sequencing principle and represent breaks in the operation sequence.

Three indices were derived from the data contained in Table 5. The first of these was the total number (N) of displays and controls used in performing a sub-task. For the 14E10 localization sub-task (Table 5), N equalled 10. The second index was the total number of response actions (TA) comprising the sub-task. In the 14E10 localization sub-task TA equalled 21. Finally, a total link value (LV) was obtained for each sub-task. In the example being used (Table 5), LV equalled 1334.4.

Based upon data contained in Figures 1 and 3 and in Table 5, five of the major indices described by Fowler, et al. (1968) were derived. The first of these (SS) expressed the degree to which the sequencing principle was applied to the console under consideration. It was calculated from the following formula:


9
1
2
3
4
5
6
7
8
10
100
128.7
300
100
55.5
100
20
20
180
55.5
55.5
100
100
14.5
57.2
14.5

$$S\% = \frac{2\left[100 \cdot \frac{OR}{OR_{max}}\right] + \left[100 \cdot \frac{L}{L_{max}}\right]}{3}$$,where

OR = LV minus total link values which are breaks in the operation sequence on the actual panel

OR_{max} = Same as above from the panel lay-out diagram (Figure 3).

L = Total number of sequencing lines on the actual panel.

L_{max} = Total number of solid lines representing left-to-right links in the panel lay-out diagram (Figure 3).

For the IF10 localization sub-task

$$S\% = \frac{2\left[100 \cdot \frac{686.6}{913.3}\right] + \left[100 \cdot \frac{0}{2}\right]}{3} = 50\%.$$

A second major index (AA%) reflected the extent to which the sub-task involved few or many alternative action choices out of each hardware item. The percentage of alternative actions present in a panel operation was given by the formula:

$$AA\% = 100\left(\frac{AA - AA_{min}}{AA_{max} - AA_{min}}\right)$$, where

AA = the total link value (LV) for an operation

AA_{max} = $100(TA)$, where TA = total number of response actions

AA_{min} = $100\left(\frac{TA}{N-1}\right)$, where N = number of controls and displays.

In the IF10 localization sub-task $TA = 24$, $N = 10$, and

$$AA\% = 100\left(\frac{1331.1 - 266.7}{2400 - 266.7}\right) = 50\%.$$

A third major index, breaks in operation sequence (BOS%), expressed the degree to which it was necessary to employ controls and displays already used within the sequence of operations, or to use controls and displays employed predominantly during later stages of the operation sequence. These "reversals" or "jumps" represented breaks in the operation sequence and were reflected in the following formula:

$$BOS\% = 100-\left(\frac{100\ BOS}{BOS_{max}}\right) \quad \text{, where}$$

BOS = the frequency of links which are "reversals" or "jumps"

$$BOS_{max} = TA - N + 1$$

In the 14E10 localization sub-task

$$BOS\% = 100-\left(\frac{100 \cdot 14}{15}\right) = 7\%.$$

A fourth index (F%) related to the relative frequency of use of display and control components. In essence it represented the degree to which the use of various components coincided with their arrangement in optimum reach envelopes. The index was given by:

$$F\% = 100-\left(\frac{100F}{F_{max}}\right) \quad \text{, where}$$

$$F = \left|\frac{TA_1}{N/3} - 1\right| + \left|\frac{TA_2}{N/3} - 1\right| + \left|\frac{TA_3}{N/3} - \left(\frac{3TA}{N} - 2\right)\right|$$

$$F_{max} = \left|\frac{4TA}{N} - 4\right| .$$

TA_1, TA_2, and TA_3 = the total actions for each of three groups of controls and displays with each group containing one third of the total number (N). The procedure used to establish the groups is given by Fowler, et al. (1968, p. 22).

In the 14E10 localization sub-task

$$F\% = 100-\left(\frac{100 \cdot 1.40}{5.60}\right) = 75\% .$$

A final index (I) was derived from information shown in Table 2. This index indicated the degree to which important hardware components were located within different zones of the panel. The index was given by the formula:

$$I\% = 100 - \left(\frac{100 I}{I_{max}}\right) \text{, where}$$

$$I = \left|I_3 - N/3\right| + \left|I_2 - N/3\right| + \left|I_1 - N/3\right|$$

$$I_{max} = \left|N/3 - N\right| + \left|N/3 - 0\right| + \left|N/3 - 0\right| .$$

I_3, I_2, I_1 = the number of controls and displays receiving importance ratings of three, two, or one (Table 2).

In the LHF10 localization sub-task,

$$I\% = 100 - \left(\frac{100 \cdot 13.5}{13.5}\right) = 0\% .$$

2.1.1.3 Additional Indices - Derivation of values for the remaining generic and specific indices was straight forward. Values for these indices were obtained primarily either from inspection of the types of data shown in Figures 1 and 3 and Tables 1 and 2, or during de-briefings with instructor personnel. As will be discussed later, however, not all of the required information (i.e., display/control ratios, signal/noise ratios, phospher decay rates, etc.) was readily available.

2.2 Predictive Methodology

Generation of a set of quantitative indices for the description of trainee (or instructor) tasks is only the first step in resolving the training prescription-prediction issue. Given a set of indices, attention must be given to their utility as predictors of learning rates or proficiency levels. The ability to make such predictions is, after all, the ultimate purpose in attempting to develop a quantitative task analysis methodology.

Use of the indices described above to predict learning rates or proficiency levels on actual Navy training devices was beyond the scope of the present effort. Nevertheless, it was felt that a demonstration of the predictive methodology would be valuable. Accordingly, a postdictive* situation was arranged. A number of learning studies having a common performance measure were abstracted from the literature and described in terms of a selected set of quantitative indices. The purpose of this effort was to determine the feasibility of using quantitative task characteristic indices to predict learning rates or proficiency levels on different tasks.

Five major steps were involved in the post-dictive exercise. These included: 1) development of a regression model; 2) selection of tasks; 3) selection of criterion measures; 4) selection and application of indices; and 5) data analysis.

2.2.1 Regression Model

A multiple-regression model was developed in which task characteristic indices were treated as predictor variables. The model was based upon the premise that the indices could be used to predict average learning rates or proficiency levels on different tasks. There were two restrictions on the model. First, tasks had to be described in terms of the same set of indices. Second, tasks had to share a common response measure (e.g., time on target, probability of detection, etc.). The rationale involved in generation of the model is presented below.

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*Postdiction simply refers to the fact that existing criterion data were used, whereas in prediction, arrangements are made to collect data in accordance with some specific experimental design. Postdiction sacrifices precise control over many variables in order to rapidly acquire a relevant set of data for analysis.

In the conventional prediction problem, subject characteristics (e.g., aptitude or ability test scores) are treated as predictor variables and are used to predict how individuals in a particular group will perform on a specific task. This leads to a multiple-regression equation which can be represented as:

$$Y_{i1} = a_{10} + a_{11}X_{i1} + a_{12}X_{i2} + \ldots + a_{1k}X_{ik} \qquad \text{(Eq. 1)}$$

where

Y_{i1} = predicted performance for individual "i" on task 1

a_{1k} = regression coefficient for the kth predictor variable

X_{ik} = score of individual "i" on predictor variable "k".

If the subject predictors in Eq. 1 were all standardized variables while the measures Y_{i1} were not, then a_{10} would equal $\bar{Y}_1$, the mean of the observed criterion measures. In Z-score form the regression equation would be:

$$Y_{i1} = \bar{Y}_1 + a_{11}Z_{i1} + a_{12}Z_{i2} + \ldots + a_{1k}Z_{ik} . \qquad \text{(Eq. 2)}$$

Equation 1 or 2 would provide information on the relevance of various subject characteristics for predicting the performance of an individual on task "1". But task "1" has its own characteristics. These characteristics are fixed. That is, they are constants which are not represented in Eq. 1 or Eq. 2, and as such they cannot influence the predictor coefficients (a_{1k}).

Suppose, however, that the original group of individuals performs on a second task (2). In addition to Eq. 2 there will now be another multiple-regression equation:

$$Y_{i2} = \bar{Y}_2 + a_{21}Z_{i1} + a_{22}Z_{i2} + \ldots + a_{2k}Z_{ik} . \qquad \text{(Eq. 3)}$$

If the two equations (Eq. 2 and Eq. 3) differ only with respect to the first coefficient ($\bar{Y}_1$ and $\bar{Y}_2$), and the tasks have been measured in terms of some common performance metric, then this is equivalent to finding a significant difference between means. The difference between means can only be "explained" in terms of differences between the tasks themselves. (In the present study the attempt has been made to represent these differences quantitatively, in terms of the task characteristic indices.)

If the concept of differences between tasks and consequent differences between means is extended to a set of tasks, performed by the same group of individuals, a variable ($\bar{Y}m$) is created. It can be hypothesized that the specific values of this variable should be predictable in terms of task characteristic indices. The multiple-regression equation would have the following form:

$$\bar{Y}_m = b_{mo} + b_{m1}I_{m1} + b_{m2}I_{m2} + \ldots + b_{mn}I_{mn} \qquad \text{(Eq. 4)}$$

where

$\bar{Y}_m$ = predicted mean performance score on task "m" (e.g., $\bar{Y}_1$ in Eq. 2, or $\bar{Y}_2$ in Eq. 3, etc.)

b_{mn} = regression coefficient for the nth task index predictor variable

I_{mn} = index value for task "m" on task index "n".

Equation 4, therefore, was explored during the post-dictive study.

2.2.2 Selection of Tasks

Four criteria were established to aid in the selection of studies which could be used in the post-dictive exercise. The first criterion arose from the need to express the performance measures in terms of a common metric. Consequently, only those studies were considered which reported a "percent time on target" performance measure. These were studies in which various tracking tasks were employed. The second criterion required that a learning curve be reported in which data were available for at least ten different points in time. A third criterion was that each data point in the learning curve be based on a minimum of 10 observations. The fourth and final criterion was that there could be no change in experimental conditions over the course of the learning curve (e.g., administration of a drug after the fifth session, etc.).

Approximately 950 studies were examined in terms of the four criteria. From this sample a set of only 22 studies met all four criteria! These studies represented the following kinds and numbers of simple laboratory tracking tasks:

a) rotary pursuit (6);
b) two-hand coordination (4);
c) pedestal sight manipulation (3);
d) specialized tracking tasks (3);
e) rudder control (2);
f) turret pursuit (1);
g) pilot simulator (1);
h) Iowa pursuit apparatus (1);
i) wheel turning (1).

This sample was used as a basis for generating the desired regression equation. The specific studies which were employed are referenced in Appendix D.

2.2.3 Criterion Measures

The basic learning data for each of the 22 studies consisted of the percent time on target ("TOT) attained in relation to the number of minutes of practice on given tasks. Three types of criterion measures were derived from these data including:

1. the percent time-on-target attained after 1.25, 5, 10, 15 and 20 minutes of practice;
2. the amount of practice (expressed in minutes) required to reach TOT proficiency levels of 41%, 51%, 61%, and 71%; and
3. the increments in %TOT after 10, 15, and 20 minutes of practice against a %TOT base-line at five minutes (e.g., %TOT at 10 minutes minus %TOT at five minutes, etc.)

The first two sets of criterion measures addressed themselves to the effects of practice on proficiency levels. The third set was employed to obtain measures reflecting rates of learning. These measures were adjusted in terms of an early level of proficiency in an attempt to equate the different subject samples on early skill levels.

Unfortunately, all twelve criterion measures were not available for each of the 22 tasks sampled. For example, subjects in some studies failed to reach 71%TOT; in some studies 20 minutes of practice was not given. The net result of this attrition was that different numbers of studies were available for different criterion measures. Because the sample was small to begin with, criterion measures were employed for which a minimum of 18 studies was available. The three criterion measures finally employed were: 1) %TOT after five minutes of practice; 2) the time (minutes) required to reach a TOT level of 41%; and c) the increment in %TOT between five and 15 minutes of practice.

2.2.4 Application of Indices

The twenty-two tracking studies were obtained in their original forms from the literature; when references were given to more complete descriptions of apparatus these were also acquired. Each tracking task was described in terms of 18 task characteristic rating scales. The scales were applied by two trained raters who worked independently.

Upon completion of the ratings, the results were compared and an average set of ratings was derived for each tracking task under the following rules. The two ratings on each scale were averaged if they were no more than two points apart. If they differed by more than two points, they were discussed in the presence of a third rater who served as a final arbiter. Approximately 25 percent of the 396 ratings (i.e., 18 indices applied to 22 tasks) required arbitration. It should be noted, parenthetically, that five more scales were applied to the 22 tracking studies than were used to describe the trainee sub-tasks in the sonar training devices. This increment resulted from the use of certain indices (e.g., degree of muscular effort involved) which seemed germane to the variety of tasks sampled from the literature but which did not seem relevant to surveillance system sub-tasks.

The DEI and major panel lay-out indices could not be applied to the types of simple, laboratory tracking tasks taken from the literature. Nevertheless, an additional set of 10 indices was also applied to the tracking tasks including such descriptors as: 1) number of tracking dimensions; 2) number of control elements; and 3) number of display bits. Consequently, each of the 22 tasks was described in terms of 28 indices.

In regression analysis, however, the number of predictors should never approach, let alone exceed, the number of cases sampled. As the number of predictors approaches the number of cases sampled, the multiple-regression coefficient becomes spuriously large and uninterpretable. In the present study, therefore, five rating-scale indices were selected as the basis for one analysis, and five "human-engineering" indices were used in another analysis. Indices were selected from the total set of 28 on three bases: 1) hypothesized relevance to the criterion measures; 2) relatively low intercorrelations with other indices; and 3) normality of distribution.

The five rating-scale indices included:

a) degree of muscular effort involved (MUSC);
b) simultaneity of responses (SIMU);
c) number of output units (UNIT);
d) number of responses (NO. R); and
e) variability in stimulus location (VARS).

The five additional indices selected for separate analysis included:

a) number of tracking dimensions (TRAC);
b) number of control elements (CONT);
c) number of display digits (DISD);
d) length of duty cycle (DUTY); and
e) ratio of practice time to duty cycle (WORK).

2.2.5 Data Analysis

Six multiple-regression analyses were conducted by evaluating the two independent sets of predictors in terms of the three criteria specified above. Three additional analyses were also conducted in which predictors from the two different sets were combined. The multiple regression coefficients were generated by performing linear step-wise regression analyses. All analyses were conducted on an IBM 1130 computer using standard statistical programs.

3.0 RESULTS AND DISCUSSION

Two different sets of results are described and discussed in this section. The first set of results concerns the attempt to apply quantitative indices to information obtained from an analysis of trainee sub-tasks in sonar training devices. The second set relates to the modification studies which were undertaken.

3.1 Task Indices

Task-analytic information was derived in order to apply two different sets of quantitative indices. Generic indices were used which cut across trainee sub-tasks. They were comprised of DEI, panel layout and task-type, rating-scale, and miscellaneous indices. The second set of indices were more specific. They were relevant to some but not to all of the trainee sub-tasks.

3.1.1 Generic Indices

Task-analytic data obtained from sonar training devices were used to derive the "human-engineering" and miscellaneous index values summarized in Table 6 and the rating-scale index values shown in Table 7. In both tables, index values are presented for each trainee sub-task and device. Mean values for each sub-task are also shown to facilitate examination of the data.

3.1.1.1 Display Evaluative Index - As shown in Table 6 the DEI appears to discriminate well both among and within trainee sub-tasks. Lowest information transfer (smallest DEI values) is shown for the set-up and classification sub-tasks. The relatively low values for

Table 6

Generic "Human Engineering" Indices Derived From Task Analysis Data

Sub-Task	Device	DEI X10^{-4}	TA	N	LV	S%	BOO%	AA%	F%	#CRS	#FERS	#IARS	#IIRS
		"Human-Engineering" Indices	Panel Lay-Out Indices							Miscellaneous Generic Indices			
Set-Up	14E3 (Orig.)	33.3	30	22	2199.9	43	11	72	87	17	8	5	4
	14E3 (Revised)	39.7	24	22	2200	24	33	92	47	14	9	2	4
	14E10	13.9	37	25	2499.8	36	9	68	32	27	10	0	5
	AN/SQS-26CX	7.8	37	28	2699.9	29	10	72	39	21	15	1	4
	Mean	24	32	24	2400	33	15	75	78	19	10	2	4
Detection	14E3	17.7	8	4	500	47	40	44	57.5	3	3	2	0
	14E10	31.9	17	9	399.7	44	33	45	[illegible]	12	[illegible]	5	3
	AN/SQS-26CX	[illegible]	12	5	620	33	37.5	56	21	4	3	5	0
	Mean	33	12	6	573	41	37	42	21	6	2	4	1
Classification	14E3	49.1	7	5	399.9	47	33	43	50	3	2	2	0
	14E10	26.6	24	10	1334.4	50	7	50	75	[illegible]	7	9	[illegible]
	AN/SQS-26CX	37.5	23	11	[illegible]	42	[illegible]	57	42	9	5	[illegible]	[illegible]
	Mean	37	18	9	1049	46	[illegible]	50	73	[illegible]	4	[illegible]	[illegible]
[illegible]	14E3	3.5	19	[illegible]	1016.[illegible]	54	17	46	91	7	[illegible]	[illegible]	[illegible]
	14E10	27.7	[illegible]	6	966.7	59	25	[illegible]	100	[illegible]	[illegible]	[illegible]	0
	AN/SQS-26CX	6.5	[illegible]	6	131.3	41	4	77	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Mean	16	15	6	932	53	17	47	96	5	2	7	[illegible]

classification reflect the poor classification performance which has been reported both for passive and active sonar surveillance (Levy and Mirabella, 1968). This result lends credance to the diagnostic value of the DEI. Further credance is obtained from a comparison of the values derived for an original and a revised set-up procedure on the 1H5. The original sequence given to the investigators by the 1H5 instructor included steps which appeared to be inappropriate (i.e., using controls instead of indicators for feed-back) and unduly repetitive. Therefore, the procedure was revised slightly, and the DEI recalculated. The outcome was an improvement in information transmission.

The DEI requires detailed task-analytic information for its extraction. Given that information, however, extraction of the DEI is for the most part routine. The major difficulty encountered was determination of the number of states which controls, and in particular, displays could assume. An example of this problem was determination of the number of display states for various uses of the PPI. To deal with this problem a number of conventions were adopted which were consistent from analysis to analysis. Other analysts such as Siegel, however, possibly might have applied other interpretations. For example, when the PPI was used for tracking, a nine-state display was assumed for both bearing and range controls. Whether the operator was manipulating his bearing or range hand-wheel he had to "read" cursor position _vis à vis_ the target in one of nine basic locations (e.g., on bearing, leading, lagging: on range, short, long; and two-way combinations of these).

In general, however, application of the DEI was straight-forward. Values could be obtained fairly quickly, reliability did not appear to be a problem, and the index differentiated sub-tasks and devices. The

DEI possessed diagnostic value and was intuitively satisfying, varying in accordance with subjective impressions of sub-task difficulty.

3.1.1.2 Panel Lay-Out and Task-Type Indices - The seven panel lay-out indices shown in Table 6 also differentiated between and within sub-tasks. The largest number of responses (TA) and control and display components (N) were found in the set-up sub-tasks, while these same sub-tasks also possessed the largest link values (LV). Of interest was the fact that fairly large link values were also found for localization and classification, sub-tasks involving few displays and controls. In these cases the large link values reflected the cyclic or repetitive nature of performance. Fewer controls and displays were utilized than during set-up, but they were employed more frequently.

Values obtained for the sequencing technique index (S") can vary from zero to 100. The higher values on this index reflect relatively better panel lay-outs in terms of certain sequencing principles which are intended to enhance operater performance. With this interpretation in mind, two features of the S" data shown in Table 6 are of interest. First, within each of the three devices, as one moves from set-up through detection, localization, and classification, the S" values increase successively. These data suggest that the sonar stacks have been designed to facilitate classification performance, at least in terms of panel lay-out, with compromise designs being employed in the other sub-tasks. Second, the S" values associated with the original and revised 14E3 set-up sub-tasks appear to be inverted (i.e., the higher value might have been expected for the revised procedure). There is no inconsistency however. The data simply suggest that if one is to revise an inefficient procedure, one must also revise the panel lay-out upon which that procedure is based.

Interpretation of the "best information sequence" (BIS), "alternative actions" (AA), and "frequency of use" (FU) indices is difficult. The indices do not represent some sub-tasks. (An "importance of use" (IU) index was not shown in Table 3; it failed to provide differentiation and was dropped from the analysis because of difficulties in application to training situations.) They can vary between zero and 100 with the higher values theoretically representing better design. These particular indices, however, appear to be somewhat more labile than others. Again referring to the operational and revised set-up portion of the LPS operation, BIS and AA each tripled while FU was halved. Performance on an operation as simple as this would not be expected to change by such magnitudes. The general impression is that lability in these indices can become a major problem in sub-tasks involving few responses. More data are required, however, before this point can be resolved.

The panel lay-out indices require the same type of detailed task-analytic information needed to generate the DEI. The panel lay-out indices which are based on percentages, however, are much more difficult to generate than the DEI, and are conceivably less reliable. The basic problem lies in translating the task-analytic data into the panel lay-out diagram which is the key to several of the indices. In this study "ties" between the link values associated with different links were found repeatedly (Table 2). Fowler, et al. (1968) failed to discuss this case or guidelines for dealing with it. Perhaps this is because they have never, insofar as can be determined, applied their indices to real-world tasks. In any event, a number of conventions were adopted in the present study to resolve this problem, but the conventions involved a greater degree of judgment than seemed desirable. More rigorous rules need to be developed in this area before the indices can be used with complete confidence.

3.1.1.3 <u>Miscellaneous Generic Indices</u> - The third group of indices shown in Table 6 represented an attempt to analyze the total number of trainee actions (TA) into more specific types. These included:

a) control responses (#CRs) which were direct manipulations of controls in response to a display reading, fixed instructions, or to the instructor's directions;

b) feedback responses (#FBRs) which represented display "readings" to corroborate the effects of control actions;

c) information acquisition responses (#IARs) which represented readings of displays to acquire information; and

d) instructor initiated responses (#IIRs) which represented cases when an instructor entered or told trainees to enter a specific value into a control.

In addition to these response-related indices, the number of non-normal repertoire responses (NNRRs), the number of redundant information sources (#RIs) and the time for sub-task completion (Time) were also ascertained for sub-tasks in each device. These three indices are not shown in Table 6 because they failed to differentiate at all. The four indices (i.e., a) to d) above) which are included in Table 6 did not differentiate as clearly among the sub-tasks as did others previously described. Nevertheless, they were easy to apply and generated data of some interest. For example, instructor initiated responses were most evident among the set-up sub-tasks. The value fell to zero for localization and classification. Similarly, the information acquisition responses varied noticeably both within and between sub-tasks.

3.1.1.4 Task Characteristic Rating Scales - Ten of the thirteen scales which were applied to the task analysis data are shown in Table 7. The three scales which are not shown were modified to provide enumerative rather than rating data. These scales correspond to the N, TA, and TEP indices previously discussed in Table 6.

The most striking feature of the data presented in Table 7 is the similarity of index values across sub-tasks. Although some differentiation both within and between sub-tasks is obtained, it is not as pronounced as that shown in Table 6. This, of course, is due to the fact that most of the ratings were based upon seven-point scales. Consequently, the range of possible index variation was very restricted relative to the ranges possible for other indices. The restricted range of values which the scales can assume is not necessarily a liability. Even within this small range different scale values may actually reflect differences in performance.

Insofar as possible, however, the rating scales employed in the present study should be revised. Many of the constructs upon which the scales are based seem valuable. However, other means for their quantification should be considered. More direct measurement of these task characteristics would not only enhance index reliability, but would also permit a greater range of variation. These modifications would result in indices which are sensitive to differences among fairly complex tasks, differences which at present are possibly being minimized.

3.1.2 Specific Indices

In addition to the various generic indices described above, the attempt was made to apply a set of 15 specific and 10 training technique indices. The results were generally inconclusive (i.e., many specific indices could not be applied; when they could be, they did not clearly discriminate among tasks; and training indices were simply binary statements about the presence or absence of a "freeze" capability, for instance). Indices which could not be readily applied included range in signal to noise ratio (S/N), bearing and range control-display ratios, and signal persistency. S/N was directly manipulable only on the CX. The

Table 7

Task Characteristic Ratings Derived From Task Analysis Data

Sub-Task	Device	UNIT	DURA	LOAD	FREQ	SEQU	RATE	MODE	MADE	OCCR	VARS
		Task Characteristic Scales									
Set-Up	14E3 (orig.)	1	4	4	4	0	4	5	1	4	7
	14E3 (revised)	1	4	4	4	0	4	5	1	4	7
	14E10	1	4	2	4	0	5	6	2	5	7
	AN/SQS-26CX	1	4	2	6	2	4	5	2	6	7
	Mean	1	4	3	4.5	.5	4.3	5.3	1.5	4.8	7
Detection	14E3	1	4	2	4	0	4	2	2	4	6
	14E10	1	4	6	2	0	4	6	4	3	3
	AN/SQS-26CX	1	4	4	2	0	3	2	2	4	2
	Mean	1	4	4	2.7	0	3.7	3.3	3.3	3.7	3.7
Localization	14E3	1	4	3	6	2	4	3	2	3	4
	14E10	1	4	2	5	3	6	2	3	3	4
	AN/SQS-26CX	1	1	4	6	0	6	2	2	3	3
	Mean	1	3	3	5.3	1.7	5.3	2.3	2.3	3	3.7
Classification	14E3	1	4	6	5	2	5	6	1	7	5
	14E10	1	4	6	3	2	4	6	3	3	4
	AN/SQS-26CX	3	3	5	1	0	4	2	2	3	4
	Mean	3.7	3.7	5.7	3	1.3	4.3	4.7	2	4.3	4.3

other devices, using tape inputs, made use of unspecified ratios. Control-display ratios presented a problem since they varied with range scale and therefore no single value could be obtained. The persistency index required information about phosphor decay rates which was not readily available. However, all these indices are potentially available to a system designer and they are significant for the training process (Corcoran, Carpenter, Webster & Woodhead, 1968; Maclie & Parabedian, 1964; Mirabella, 1969; Wickens & Cotterman, 1958; Short & Baughey, 196?). Therefore future attempts should be made to include them in a predictive scheme.

The remaining 11 specific indices (see pp. 17-18) could be applied but appeared to be of limited value. Some such as variation in target range and speed and sequencing of problems were applicable across detection, classification and localization sub-tasks. These indices provided for little discrimination among devices and for no discrimination within a device (i.e., problem characteristics were not varied across sub-tasks within devices). Other specific indices were applicable to only one of the four sub-tasks. Some, such as bearing and range error tolerance and especially number of tracking dimensions did not discriminate well. Others did vary among devices. These included: number of cues available for classification, number of cues used simultaneously, number of false targets used, target to non-target ratio, and number of contacts per minute. Values for these indices were fairly unstable, however, since they were merely rough estimates, given by instructors, of the materials appearing on various tapes. Finally, information about different training techniques was of little value for the purpose of the present study, because they provided no differentiation among sub-tasks within devices, and little if any discrimination among the devices sampled.

With few exceptions, the specific task indices appeared to be arbitrarily chosen or fixed by equipment design. The lack of flexibility, in the taped devices particularly, was emphasized to the investigators.

5.2 Prediction Studies

5.2.1 Rating Scales

Five task characteristic rating scales were used to predict the criterion of percent-time-on-target (%TOT) after five minutes of

Table 8

Multiple Regression Analyses

Analysis	Predictors	Criterion	No. Ss	No. Pred.	R	R^2	p
1	UNIT SIMU NO.R MUSC VARS	% TOT at 5-min.	20	5	.78	.60	[illegible]
2	Same as #1	41% TOT	18	4	.65	.42	n.s.
3	Same as #1	Adj.15-min. % TOT	18	5	.55	.31	n.s.
4	TRAC CONE DISD DUTY WORK	% TOT at 5-min.	20	4	.6[illegible]	.42	<.10
5	Same as #4	41% TOT	18	4	.68	.46	<.10
6	Same as #4	Adj.15-min. % TOT	18	4	.48	[illegible]	n.s.
7	UNIT NO.R VARS TRAC CONE	% TOT at 5-min.	20	5	.82	.67	<.01
8	NO.R VARS DISD DUTY WORK	41% TOT	18	5	.78	.61	<.05
9	SIMU NO.R VARS CONE DUTY	Adj.15-min. % TOT	18	5	.57	.32	n.s.
10	Same as #7	% TOT 10-min.	19	5	.74	.55	<.05

Table 8 (Continued)

Analysis	Predictors	Criterion	No. Cases	NO. Pred. Used	R	R^2	P
11	Same as [illegible]	% TOT 15-min.	20	5	.64	.41	n.s.
12	NO.R VARS DISD DUTY WORK	% TOT at 5-min.	20	4	.63	.40	$<.10$
13	Same as #12	% TOT at 10-min.	19	5	.71	.51	$<.10$
14	Same as #12	% TOT at 15-min.	20	4	.69	.48	$<.05$

UNIT: number of output units
SIMU: simultaneity of responses
NO.R: number of responses
MUSC: degree of muscular effort involved
VARS: variability in stimulus location
TRAC: number of tracking dimensions
CONE: number of control elements
DISD: number of display digits
DUTY: length of duty cycle
WORK: ratio of practice time to duty cycle

practice. The results, shown in Table 8 as Analysis 1, indicate a multiple R of 0.78 which accounts for 60% of the variance in the criterion measure; the correlation was significant beyond the .05 level of confidence. This criterion was viewed as the initial level of proficiency (an earlier proficiency level obtained at 1.25 minutes was not used due to the smaller number of studies yielding this measure).

These same five rating scales were then entered into regression analyses to predict two other criterion measures: 1) the time required to reach 41% TOT, and 2) an adjusted % TOT achieved after 15 minutes of practice. The latter measure was derived by subtracting the % TOT at five minutes from that reached at 15 minutes, i.e., it reflected the increment in % TOT over the initial proficiency level. As indicated in Table 8, neither of these analyses (#2, #3) yielded a significant multiple R ($p > .10$). A tentative hypothesis was formed which suggested that the task characteristic scales had maximum predictive efficiency for initial levels of performance rather than performance levels achieved later in training.

3.2.2 "Human Engineering" Indices

Analyses aimed at predicting these same three criterion measures were then conducted using five "human-engineering" indices. These indices, shown in Table 8 as analyses 4, 5, and 6, yielded two multiple R's which were significant at a less stringent level of confidence ($p < .10$); the 0.10 confidence level was considered appropriate for this exploratory work. The two criterion measures successively predicted were the initial level of performance (% TOT at five minutes) and the time required to reach the 41% TOT level. Contained within the set of "human engineering" indices were two predictors, duty-cycle length and work ratio, which reflected the distribution of practice dimension inherent in all of the studies. An examination of their contributions to the predicted variance indicated that they were minimally involved in predicting initial performance but made increasing contributions to prediction of the later performance level of 11th TOT. These findings are logical in that one would not expect predictors representing a distribution of practice variable to be as effective in predicting earlier proficiency as they might be later in the course of training. The remaining three indices had their highest predictive efficiency in regard to the initial performance criterion.

In general then, the five task characteristic scales and three of the "human engineering" indices performed best in predicting starting levels of performance; increases in predictive efficiency for later performance were noted for the two predictors representing distribution of practice.

The results from the analyses up to this point are understandable on a *post hoc* basis when it is recognized that the rating scales and "human engineering" indices are mainly descriptive of the task *per se* and not of the training regimen or conditions of learning under which the task was performed. The training variables were minimally reflected in the two predictors representing the distribution of practice dimension; these nevertheless did show increasing contributions to prediction when a criterion involving later performance was used.

3.2.3 Combined Indices

The next step taken in the analysis was to create a new set of predictors based on the "best" predictors from the task-characteristic scales and the "human-engineering" indices. The composition of this combined set varied in accordance with the criterion being predicted. Table 8 shows which combination was used for each of the three criterion measures.

The net effect of combining the scales and indices was to increase the multiple R's obtained for the initial performance level and the 41% TOT criteria. Multiple correlations of 0.82 ($p < .01$) and 0.78 ($p < .05$) were obtained, respectively. The combined set of predictors yielded no increase in prediction of the criterion measure of the adjusted 15-minute % TOT nor was the multiple-correlation significant ($p > .10$). These analyses are represented in Table 8 as 7, 8, and 9.

At this point in the analysis it was decided to investigate further the hypothesis that the rating scales and indices were primarily predictive of initial rather than interim performance. To test this point two additional criterion measures, % TOT at ten and 15 minutes, were used. The predictors employed were the combined set which had been maximally effective for the five-minute initial level of performance (see analysis 7 in Table 8). The result of these two regression analyses (10 and 11 in Table 8), lent support to the hypothesis in that the multiple correlations decreased as the length of practice represented by the criterion increased. These relationships are shown below.

Criterion	Multiple R	P
% TOT 5-min.	.82	$<.01$
% TOT 10-min.	.74	$<.05$
% TOT 15-min.	.64	NS

Having demonstrated, within the limits of the study, that the majority of the scales and indices had their maximal predictive efficiency for the starting level of performance, one further set of analyses was conducted to test the prediction limits for interim performance. In these analyses (12, 13, and 14 in Table 8), the set of predictors used were those previously employed to predict 41% TOT (analysis 8). Contained in this set were the distribution of practice predictors. Using the "best" scales and indices plus the duty-cycle and work-ratio predictors, regression analyses were run with the five, ten and 15-minute % TOT criteria. The results, shown below, indicate that this combination of predictors effectively extended the predictive efficiency to interim levels of performance:

Criterion	Multiple R	P
% TOT 5-min.	.63	<.10
% TOT 10 min.	.71	<.10
% TOT 15-min.	.69	<.05*

An examination of the individual predictors across practice time (i.e., five, ten, and 15-minutes) again indicated that duty-cycle and especially work-ratio made increasingly greater contributions to the amount of predicted variance as practice time grew longer. A similar increasing contribution was also found for the "number of responses" predictor; a recheck of this predictor's contribution across practice time was made in analyses 10 and 11 and a similar profile appeared. Thus, it would seem that at least three of the indices are capable of extending predictive efficiency to the interim levels of performance.

3.2.4 Discussion

An overall appraisal of the findings of the 14 regression analyses indicates, first, that the criterion measures used in the post-diction studies are of two distinct types. Initial level of performance, the first type, appears to be predicted most efficiently by descriptors which relate to features of the task *per se*. The majority of the scales and indices are directed to just this point. At initial levels of performance, the training variables used in the studies have had little if any impact. Dominant factors at this stage are probably aspects of the task itself and the abilities of the subjects.

*This "lower" correlation has a higher p-value due to the slightly larger number of cases contributing to it as compared to the R of .71 directly above it.

It is conceivable that the bulk of the residual variance in the initial performance predictions resides in the subject factor. Several studies (Fleishman 1957, 1960; Fleishman and Hempel, 1954, 1955; and Hinrichs, 1970) have shown that the abilities of subjects are related to or predictive of performance on a variety of tasks. These studies have also indicated, however, that the pattern of abilities contributing to proficiency on complex tasks may change as practice on such tasks continues and proficiency increases.

When attention is focused on predicting interim performance levels, the second type of criterion measure, predictive efficiency of the majority of the predictors declines. One potential explanation for this decline would be the increasing impact of whatever training variables are in effect plus the interaction of these variables with subject characteristics. The analyses indicate that changes in the predictive contributions of the various indices occur when the criterion measures reflect interim rather than initial performance. A smaller number of the predictors appear to come into their own when later performance is examined. Understandably, some of these predictors relate to the important training dimension of distribution of practice, i.e., massed versus spaced practice. In a less readily understood case, the predictor variable of "number of responses" also increased in predictive efficiency as practice time increased.

Had other types of task-characteristic indices been used in the post-diction study (e.g., DEI and panel indices), their predictive efficiency might have increased as proficiency increased. If obtained, this finding would be of interest when compared with studies on the contribution of subject variables (abilities) to different stages of practice (e.g., Fleishman, 1960; Hinrichs, 1970). These and similar studies have generally shown decreasing predictions from ability variables with continued practice and higher proficiency levels on the criterion tasks. At the same time they have identified "task-specific" factors which increase in importance as proficiency increases. An interesting area of research would be to determine whether the "task-specific" factors found in such studies can be related to or explained in terms of task-characteristic indices. The simultaneous use of subject, task, and training indices might enhance predictive efficiency.

Granting all of the limitations inherent in the post-diction study, its results confirm the initial conceptualization of the training situation which viewed it in terms of the task *per se*, the subjects, the training variables, and interaction among these components. The evidence at hand indicates the need for indices specifically designed to measure aspects of each of these components.

The problems and limitations of the post-diction are many and should not be slighted. The attrition experienced as the search went on for suitable studies in the open literature placed a decided limitation on how far the results of the regression analyses may be generalized. The small number of studies acquired did not permit the important step of cross validation to be taken. Use of the literature itself removed any control over the subject factor and prevented application of the DEI and panel lay-out indices. Yet in spite of these factors, sizeable portions of the total variance in performance were predictable using the indices applied. Shrinkage of these figures would undoubtedly occur upon cross validation but their continued development still appears justified.

The development should proceed, in three directions. First, refinement of the rating scales must be undertaken. Several instances were encountered during both the field work and the post-dictive studies in which inter-rater agreements were lacking. Agreement can be improved by providing more concise and consistent definitions for the rating-scale indices. Agreement would also be improved to the extent that the concepts represented by the scales can be measured or enumerated more directly.

Second, attention must be given to development of training technique indices. Results of the post-diction exercise suggest that such indices may aid in the prediction of advanced levels of proficiency. Whether these indices would be as necessary in dealing with complex training devices as they appear to be when studying simple laboratory tasks remains to be seen. Third, and finally, the types of indices employed in the present study must be applied to actual training devices for which performance criteria are available. The demonstration of relationships between quantitative task indices and performance measures in highly complex man-machine tasks would be truly impressive.

1.0 CONCLUSIONS

This study has demonstrated the feasibility of using a variety of quantitative indices to describe salient characteristics of the trainee sub-tasks found in surveillance system training devices. Although applied only to trainee sub-tasks in selected sonar systems, many of the indices nevertheless appear applicable to a wide variety of both trainee and instructor tasks.

The importance of this demonstration is evident when one considers the nature of many of the quantitative indices which were employed. First, several of the measures, and in particular the DEI and panel lay-out indices, are directly related to features of a task familiar to design engineers. These are hardware and procedural features which might be reconfigured during the development of alternative designs. Modifications of these task characteristics would be reflected by changes in the values of many of the quantitative task indices employed in the present study. Second, and more importantly, these same task characteristics can be hypothesized to bear a relationship to measures of task performance including proficiency levels or rates of skill acquisition. Fowler, et al. (1968) have already demonstrated this type of relationship for some of their panel lay-out indices.

In theory, therefore, the possiblity exists of developing quantitative profiles of tasks and of relating such profiles to measures of performance. Were information of this type available, it would then be possible to predict the behavioral consequence of restructuring a task's profile of quantitative indices. A basis would exist for predicting the effectiveness of alternative training device designs. All of this is contingent, of course, upon the demonstration of a relationship between the quantitative indices and measures of performance.

Results of the post-diction study conducted during this project confirmed the existence of significant relationships between "task characteristic indices" and measures of performance. The relationships were strongest ($p < .05$) during early stages of practice. However, nine of the 14 multiple-correlation coefficients which were computed suggested the presence of relationships between task indices and criterion measures of performance ($p < .10$). These results were particularly encouraging, being obtained in spite of the fact that the major indices of interest (DEI and panel lay-out indices) could not be employed, and that differences between groups of subjects (a violation of the predictive model) could not be avoided.

The major conclusion of this study is that further development of a quantitative task analytic methodology is warranted. If the types of indices employed in this study can be related to behavioral measures obtained in training devices, an invaluable tool can be developed for individuals responsible for sound training decisions. At the very least this approach would put the device design process on a more objective footing.

5.0 RECOMMENDATIONS

As has been discussed in earlier sections of this report, development of a set of quantitative indices for the description of tasks is only the first step in a larger program of research. To be of applied value it must be demonstrated that changes in the design of a training device (i.e., changes in the trainee's or instructor's station and tasks) are reflected in corresponding quantitative task indices. Similarly, it must be shown that variations in the quantitative indices are related to different rates of learning or levels of proficiency.

Additional research will be required to demonstrate these relationships. For a number of reasons, however, the investigation will be difficult to execute satisfactorily. These problems stem from the requirement that the research focus on actual training devices currently in use in the field.

The major recommendation stemming from the present report is that a predictive study be undertaken, based on actual training devices. As the first step in this study, additional quantitative indices should be assembled. Emphasis should be placed upon use of indices previously developed and reported in the literature, rather than on the development of new indices. Most desireable would be indices possessing the following attributes: 1) construct validity; 2) ease of quantification and reliability; 3) generic applicability across devices, and 4) based upon task features of relevance to design engineers.

The assembled indices should be applied to a large sample of both trainee and instructor tasks for which criterion data are available.

In this future effort consideration should be given to use of a wider variety of criterion measures. In addition to rate of learning and level of proficiency, consideration should be given to transfer of training criteria. Similarly, measures of instructor proficiency during device operation must be entertained.

If the results of these efforts were promising, then a number of interactive studies should be undertaken. These studies would attempt to generate guidelines about the personnel who would benefit most from training, and about the training techniques which could be applied to particular tasks to increase training effectiveness. The key to this research, however, is to first understand the relationships between different tasks and the performance of those tasks.

REFERENCES

Berliner, D. C., Angell, D., & Shearer, J. Behaviors, measures, and instruments for performance evaluation in simulated environments. Paper delivered for a Symposium and Workshop on the Quantification of Human Performance, (1964). Albuquerque, New Mexico.

Bilodeau, E. A., & Bilodeau, I. McD. Motor skills learning. Annual Review of Psychology, 1961, 12, 243-280.

Caro, P. W. Adaptive training - An application to flight simulation. Human Factors, 1969, 11, 569-576.

Chapanis, A., & Gropper, B. A. The effect of the operator's handedness on some directional stereotypes in control-display relationships. Human Factors, 1968, 10, 303-320.

Chenzoff, A. P., & Folley, J. D., Jr. Guidelines for training situation analysis (TSA). Technical Report 1218-4(1965). Naval Training Device Center, Orlando, Florida.

Corcoran, D. W. J., Carpenter, A., Webster, J. C., & Woodhead, M. M. Comparisons of training techniques for complex sound identification. Journal of the Acoustical Society of America, November, 1968.

Cofer, C. N., & Appley, M. H. Motivation: theory and research, New York: John Wiley & Sons, 1964.

Farina, A. J., Jr., & Wheaton, G. R. Development of a taxonomy of human performance: The task characteristics approach to performance prediction. Technical Report No. 8, (In Press), American Institutes for Research, Silver Spring, Maryland.

Fleishman, E. A. A comparative study of aptitude patterns in unskilled and skilled psychomotor performances. Journal of Applied Psychology, 1957, 41, 263-272.

Fleishman, E. A. Abilities at different stages of practice in rotary pursuit performance. Journal of Experimental Psychology, 1960, 60, 162-171.

Fleishman, E. A., & Fruchter, B. Factor structure and predictability of successive stages of learning Morse code. Journal of Applied Psychology, 1960, 44, 97-101.

Fleishman, E. A. & Hempel, W. E., Jr. Changes in factor structure of a complex psychomotor test. Psychometrika, 1954, 19, 239-252.

Fleishman, E. A., & Hempel, W. E., Jr. The relation between abilities and improvement with practice in a visual discrimination reaction task. Journal of Experimental Psychology, 1955, 49, 301-312.

Fleishman, E. A., Teichner, W. H., & Stephenson, R. W. Development of a taxonomy of human performance: A review of the second year's progress. AIR-726-1/70-TPR2, (1970). American Institutes for Research, Silver Spring, Maryland.

Folley, J. D., Jr. Development of an improved method of task analysis and beginnings of a theory of training. NAVTRADEVCEN 1218-1. (USNTDC, 1964). Port Washington, New York.

Fowler, R. L., Williams, W. E., Fowler, M. G., & Young, D. D. An investigation of the relationship between operator performance and operator panel layout for continuous tasks. AMRL-TR-68-170, (December, 1968). Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

Gagne, R. M. Human functions in systems. In R. M. Gagne (Ed.) Psychological principles in system development. New York: Holt, Rhinehart, & Winston, 1962.

Hinrichs, J. R. Ability correlates in learning a psychomotor task. Journal of Applied Psychology, 1970, 54, 56-64.

Jensen, A. R. On the reformulation of inhibition in Hull's system. Psychological Bulletin, 1961, 58, 274-298.

Kientzle, M. J. Properties of learning curves under varied distributions of practice. Journal of Experimental Psychology, 1946, 34, 187-211.

Levy, R. M., & Mirabella, A. State of the art active and passive sonar classification performance for SSN(X). February 1968. EB Report C417-68-014 (Confidential).

Mackie, R. R., & Harabedian, A. A study of simulation requirements for sonar operator trainers. Technical Report: NAVTRADEVCEN 1320-1, (March, 1964.) U.S. Naval Training Device Center, Orlando, Florida.

Miller, E. E. The development of a response taxonomy. Professional Paper 32-69, (1969). Human Resources Research Organization, Alexandria, Virginia.

Miller, R. B. A method for man-machine task analysis. Technical Report 53-137, (1953). Wright-Patterson Air Force Base, Ohio.

Miller, R. B. Task taxonomy: Science or technology? Poughkeepsie, New York: IBM, 1966.

Miller, R. B., & Van Cott, H. P. The determination of knowledge content for complex man-machine jobs. (1955). American Institutes for Research, Pittsburgh, Pennsylvania.

Mirabella, A. Two-dimensional versus three-dimensional tracking under two modes of error feedback. Journal of the Human Factors Society, (1969), 11.

Morgan, C. T., Cook, J. S., III, Chapanis, A., & Lund, M. W. Human Engineering Guide to Equipment Design, New York: McGraw-Hill, 1963.

Parker, J. F., & Fleishman, E. A. Ability factors and component performance measures as predictors of complex tracking behavior. Psychological Monographs, 1960, 74(16, Whole No. 503).

Parker, J. F., & Fleishman, E. A. Use of analytical information concerning task requirements to increase the effectiveness of skill training. Journal of Applied Psychology, 1961, 45, 295-302.

Short, J., & Haughey, B. Study of sequencing strategies. Proceedings of the 75th Annual Convention of the American Psychological Association, 1967, 2, 517-518.

Siegel, A. I., & Federman, P. J. Validation of the DEI technique for large-scale display evaluation. Technical Report No. RADC-TR-67 131, (May 1967). Rome Air Development Center, Griffiss Air Force Base, New York.

Siegel, A. I., Miehle, W., & Federman, P. Information transfer in display control systems, IV. Summary review of the DEI technique. (Fourth Quarterly Report). (Applied Psychological Services, 1962a), Wayne, Pa.

Siegel, A. I., Miehle, W., & Federman, P. Information transfer in display-control systems. VI. A manual for the use and application of the display evaluative index (Sixth Quarterly Report). (Applied Psychological Services, 1962b.) Wayne, Pa.

Siegel, A. I., Miehle, W. & Federman, P. Information transfer in display-control systems, VII. Short computational methods for and validity of the DEI technique (Seventh Quarterly Report). (Applied Psychological Services, 1963.) Wayne, Pa.

Smith, B. J. Task analysis methods compared for application to training equipment. NTDC 1218-5, (September 1965). U. S. Naval Training Device Center, Port Washington, N. Y.

Stolurow, L. A taxonomy of learning task characteristics. AMRL-TP 12-64-2, Aerospace Medical Research Laboratories, (January 1964), Wright-Patterson Air Force Base, Ohio.

Tallmadge, G. K., & Shearer, J. W. Study of training equipment and individual differences: Research on interactive relationships among learner characteristics, types of learning, instructional methods, and subject matter variables. Technical Report: NAVTRADEVCEN 68-C-0271-1, June 1970, Naval Training Device Center, Orlando, Florida.

Tufts College, Handbook of Human Engineering Data. Human Engineering Report SDC 199-1-2a, [January 1960 (2nd edition)]. U. S. Naval Training Device Center, Port Washington, N. Y.

Wickens, D. D., & Cotterman, T. E. The effect of display interruption on transfer of training between tasks of different control sensitivity. WADC Technical Report 57-548, (March 1958), Wright Air Development Center, Wright-Patterson Air Force Base, Ohio.

Willis, M. P., & Peterson, R. O. Deriving training device implications from learning theory principles, Vol. I: Guidelines for training device design development and use. Technical Report 784-1, (1961), Naval Training Device Center, Port Washington, Long Island, New York.

Appendix A

Task Characteristic Rating

Scales

Note: The 13 scales used for the Key West study are indicated by asterisks (*). All of the 18 indices presented in this Appendix were employed in the post-diction study.

*1. NUMBER OF OUTPUT UNITS (UNIT)

The entire purpose of the task is to create output units. An output unit is the end product resulting from the task. Output units can take different forms. For example, sometimes the output unit is a physical object assembled from several parts. It may also take the form of a relationship between two or more things, e.g., drive three car-lengths behind the car in front of you. An output unit might also be a destination, e.g., run from here to the corner, with the corner being the destination.

First, identify what the output unit(s) is in the present task. Now, count the number of such output units that someone performing this task is supposed to produce. Use the designation AMAP (As many as possible) where no actual limit exists.

*2. DURATION FOR WHICH AN OUTPUT UNIT IS MAINTAINED (DURA)

Once the operator has produced an output unit he may be required to maintain or continue it for one of several time periods. For example, it can be maintained for as long as possible. Another alternative is that completing one output unit is a signal to leave it and go on to produce the next output unit. Or, having produced the output unit, performance ends.

Choose which of the following alternatives applies here:

1) Maintain unit as long as possible.

2) Maintain unit as long as possible but continue to produce additional units.

3) Leave unit and go on to produce next unit.

4) Production of unit signals end of task.

*3. NUMBER OF ELEMENTS PER OUTPUT UNIT (ELEM)

One way of describing an output unit is in terms of the number of elements involved in its production. By elements we mean the parts or components which comprise the output unit. In an addition problem, for example, the numbers to be added are the elements which comprise the output unit. In a more physical task, the elements could be parts to be assembled or apparatus to be manipulated.

Count the number of different displays and controls which are manipulated in producing a single output unit.

*4. SIMULTANEITY OF RESPONSES (SIMU)

The responses which the operator makes in producing one output unit may involve one or more effectors (e.g., hand, foot, arm, voice, etc.). Depending upon the task, these effectors may or may not be used simultaneously. For example, both hands (two effectors) are used simultaneously in playing a piano.

How many effectors are being used simultaneously during the present task?

zero ____? two ____? three ______ four ______

*5. NUMBER OF RESPONSES (NO. R)

Earlier we were concerned about the number of elements, i.e., objects or components, involved in the production of one output unit. Now we want to consider the number of (responses) needed to produce one output unit. There isn't a necessary one-to-one relationship between objects and responses.

Count the number of responses or steps involved in producting one output unit for the present task. Enter this number on the answer sheet.

*6. RAPIDNESS OF FEEDBACK (FEED)

For present purposes the term FEEDBACK refers to information which an operator may get about the correctness of a resnonse. Consider the maximum number of responses the operator makes before receiving feedback on the status of output unit. Enter that number on the answer sheet.

*7. WORK LOAD (LOAD)

Work load refers to the number of output units to be produced relative to the time allowed for their production. We are interested in the ratio of the number of output units per unit time, e.g., make 5 widgets in 10 minutes 1 widget produced every two minutes.

However, there are those tasks in which the goal is to maintain a situation rather than to produce multiple output units. For example, a driving task where you are to stay within 40 feet of the vehicle ahead of you. For these types of tasks, work load refers to the length of time for which maintenance is required. The longer the maintenance period, the higher the work load.

Therefore, rating a task in terms of work load resolves to answering one of two questions

1) How much has to be produced in what amount of time; or
2) How long does this situation have to be maintained or continued?

Definitions		Examples
High work load - as many output units as possible are to be produced in a fixed period of time; a relatively large number of output units is to be produced in a relatively short period of time; an output unit is to be maintained for a relatively long time or for as long as possible.	7	• Drive as many nails as possible in five minutes. • Maintain a stimulus-control relationship as long as possible.
	6	
	5	
Moderate work load - a moderate number of output units is to be produced in a reasonable period of time; an output unit is to be maintained for a moderate period of time relative to other possible periods.	4	• Drive ten nails in five minutes. • Maintain a stimulus-control relationship for three minutes.
	3	
	2	• Drive these two nails in the next five minutes. • Sum the following five numbers. • Maintain a stimulus-control relationship for 30 seconds.
Low work load - a small number of output units is to be produced in a relatively long period of time; an output unit is to be maintained for a relatively short period of time.	1	

*8. PRECISION OF RESPONSES (PREC)

Tasks may differ in terms of how precise or exact the operator's responses must be. Judge the degree of precision involved in the present task by considering the <u>most</u> precise response made in producing an output unit.

Definitions		Examples
<u>High degree of precision</u> - because of small targets, fine scales, sensitive controls, etc. the subject must make responses which are extremely precise.	7	• Using a chemical balance (scales) determine the weight of the following objects to the nearest microgram. • Replace the mainspring in this wrist-watch.
	6	
	5	
<u>Moderate precision</u> - relative to the definitions above or below, a moderate degree of precision must accompany subject's responses.	4	• Using your pencil, trace this maze.
	3	
	2	• Do twenty push-ups. • Sort the oranges and lemons into two piles.
<u>Low degree of precision</u>-because of large targets, gross scales, insensitive controls, etc. the subject can make responses which are gross or imprecise.	1	

#9. RESPONSE RATE (RATE)

Responses can be made at different rates. That is, the frequency with which responses must be made can vary from task to task. For example, you would have a higher rate of responding if you were playing a singles game of tennis than if you were playing chess. The responses would come more frequently in the first case than in the second. You are to judge what rate of responding is called for in producing <u>one</u> output unit in the task being judged.

Definitions		Examples
<u>High rate of responding</u> - many responses are required per unit time. In the extreme case responses become continuous.	7	• Fire 20 rounds for effect as quickly as possible. • Complete this jig-saw puzzle as fast as you can. • Track this target.
	6	
	5	
<u>Moderate rate of responding</u> - a moderate number of responses are required per unit time.	4	• Fire 20 rounds. Fire rapidly but also be as accurate as you can.
	3	
	2	
<u>Low rate of responding</u> - few responses are emitted per unit time. Responses are often singular.	1	• Add the following numbers. Take all the time you need.

10. NATURAL DEPENDENCY OF RESPONSES (NADE)

Consider again the number of steps (responses) involved in producing one output unit. The steps may be described in terms of the dependency among them. dependency concerns the extent to which the steps must be done in some specified order. For example, dependency exists between Steps A and B if step B cannot be accomplished without step A being done first. Note; Procedures which have only one step are automatically low in dependency. Natural dependency refers to dependency that is inherent in the operation of the equipment.

Definitions		Examples
High dependency among steps - each step in the procedure is completely dependent upon the preceding procedural step. Systematic ordering of steps is at a maximum.	7	• Using the combination you've been given, open the safe. • Dial this telephone number.
	6	
	5	
Moderate dependency among steps - in the total number of steps comprising the procedure, approximately 50% are dependent upon preceding steps.	4	• Using colored blocks, stack them into columns four blocks high. Do this in the order red and green for the first two blocks. The remaining blocks may be of any color.
	3	
	2	
Low dependency among steps - procedural steps are not organized in any particular sequence. Step 'A' may precede 'B' or 'B' may precede 'A'. Procedures having one step are low in dependency.	1	• Using colored blocks, stack them into columns four blocks high. Order of color is unimportant.

*11. TUTORIAL DEPENDENCY OF RESPONSES (TUDE)

Consider again the number of steps (responses) involved in producing one output unit. The steps may be described in terms of the dependency among them; dependency concerns the extent to which the steps must be done in some specified order. For example, dependency exists between steps A and B if step B cannot be accomplished without step A being done first. Note Procedures which have only one step are automatically low in dependency. Tutorial dependency refers to a dependency imposed as part of the training in an effort to standardize trainee operations.

Definitions		Examples
High dependency among steps - each step in the procedure is completely dependent upon the preceding procedural step. Systematic ordering of steps is at a maximum.	7	• Using the combination you've been given, open the safe. • Dial this telephone number.
	6	
	5	
Moderate dependency among steps - in the total number of steps comprising the procedure, approximately 50% are dependent upon preceding steps.	4	• Using colored blocks, stack them into columns four blocks high. Do this in the order red and green for the first two blocks. The remaining blocks may be of any color.
	3	
	2	
Low dependency among steps - procedural steps are not organized in any particular sequence. Step "A" may precede "B" or "B" may precede "A". Procedures having one step are low in dependency.	1	• Using colored blocks, stack them into columns four blocks high. Order of color is unimportant.

12. OPERATOR CONTROL OF THE RESPONSE (OCOR)

Given the occurrence of the stimulus, what degree of control does the operator have over when he must initiate his response.

Definitions		Examples
Full operator control - the operator is the sole determiner of when the response will be made.	7	• Playing a game of chess by yourself where you play both sides and there is no time limit for responding.
	6	
	5	
Partial operator control - the response must be made within a reasonable time after the stimulus occurs but the operator determines when within the interval the response will take place.	4	• The traffic light turns red when you are 500 yards from it; you have options as to when you will hit the brake.
	3	
	2	
No operator control - the operator must respond as soon as the stimulus occurs.	1	• Typical reaction time task. When the light comes on, push this button as fast as you can.

13. FEEDBACK (FEED)

For present purposes the term FEEDBACK refers to information which an operator may get about the correctness of a response. In this scale we are interested in how quickly feedback occurs once the response is made.

Definitions	Scale	Examples
Immediate feedback - Operator knows whether the response was correct as soon as it was completed.	7	• Finding the correct switch to turn on a light.
	6	
	5	
Delayed feedback - operator receives feedback regarding his responses after entire task is completed.	4	• Opening a combination lock having five numbers.
	3	
	2	
No feedback provided - Operator never receives feedback	1	• Student takes a mid-term exam but is not told what grade he got.

14. DEGREE OF MUSCULAR EFFORT INVOLVED (MUSC)

This dimension considers the amount of muscular effort required to perform the task. Examine the task and identify the most physically strenuous part of it. Rate this part on the scale below.

Definitions	Scale	Examples
High amount of muscular effort-response(s) require a high degree of muscular involvement.	7	• Do 40 push ups. • Lift the heaviest weight possible.
	6	
	5	
Moderate amount of muscular effort required for the response(s)	4	• Tighten nuts on bolts securely with a wrench.
	3	
	2	
Low amount of muscular effort required	1	• Solder two wires together • Add numbers and report the sum aloud.

15. OPERATOR CONTROL OF THE STIMULUS (OCOS)

What degree of control does the operator have over either the occurrence or relevance of the stimulus

Definitions	Scale	Examples
Full operator control - the operator is the sole determiner of when the stimulus occurs or when it becomes relevant.	7	• Shooting skeet: shooter determines when "bird" appears.
	6	
	5	
Partial operator control - the operator has some control over when the stimulus either occurs or becomes relevant.	4	• Controlling the speed of one's car [illegible] approaching a [illegible] to have a green light when [illegible] the intersection.
	3	
	2	
No operator control - the operator has no control over when the stimulus occurs or when it becomes relevant.	1	• Waiting for the telephone to ring.

16. REGULARITY OF STIMULUS OCCURRENCE (ROSO)

Consider the critical stimulus or stimulus complex to which the operator must attend. Does it occur at regular (i.e., equal) intervals or at irregular intervals. Treat regular intervals and constant presence of the stimulus as equivalent conditions.

Rate the present task on this dimension.

Definitions		Examples
<u>High regularity</u> - stimulus occurs at regular intervals or is constantly present.	7	• Cars coming along an assembly line. • Looking at a photograph of an object.
	6	
	5	
<u>Medium regularity</u> - stimulus occurs at irregular (unequal) intervals but there is a pattern of occurrence.	4	• Receiving morse code.
	3	
	2	
<u>Low regularity</u> - stimulus occurs at very irregular (almost random) intervals.	1	• Detecting random signals on a CRT display.

17. STIMULUS OR STIMULUS COMPLEX DURATION (SDUR)

Consider the critical stimulus or stimulus-complex to which the operator must attend in performing the task. Relative to the total task time, for how long a duration is the stimulus or stimulus-complex present during the task?

Definitions		Examples
<u>Long duration</u> - stimulus would remain indefinitely.	7	• Drawing a picture by observing a model of the object being drawn.
	6	
	5	
<u>Medium duration</u> - stimulus remains present until changed (spatially, temporally, etc.) by the response made to it.	4	• Red light goes out when operator pushes a button.
	3	
	2	
<u>Short duration</u> - stimulus ceases prior to response being made to it.	1	• Operator must identify words or targets presented tachistoscopically.

18. VARIABILITY OF STIMULUS LOCATION (VARS)

Judge the degree to which the physical location of the stimulus or stimulus complex is predictable over task time.

Definitions		Examples
<u>High predictability</u> - stimulus location remains basically unchanged.	7	• Stimulus is a red light located on a display panel.
	6	
	5	
<u>Medium predictability</u> - location changes but in a known manner or pattern.	4	• Visually following an arrow in flight toward a target.
	3	
	2	
<u>Low predictability</u> - location changes in an almost random fashion.	1	• Predicting which leaf will fall from a tree next.

Appendix B

Operations Flow-Charts

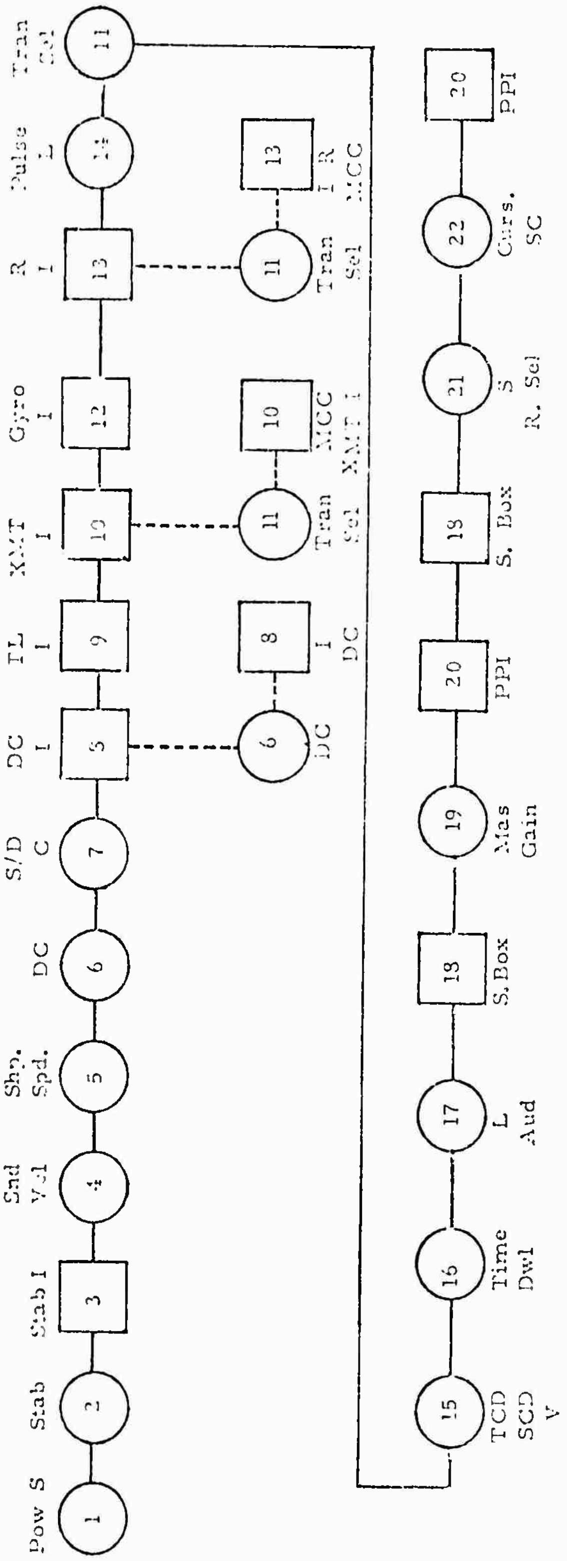


Figure 2.1. Operations Flow-Chart for the [illegible] Set-up Sub-Task (Optional Procedure)

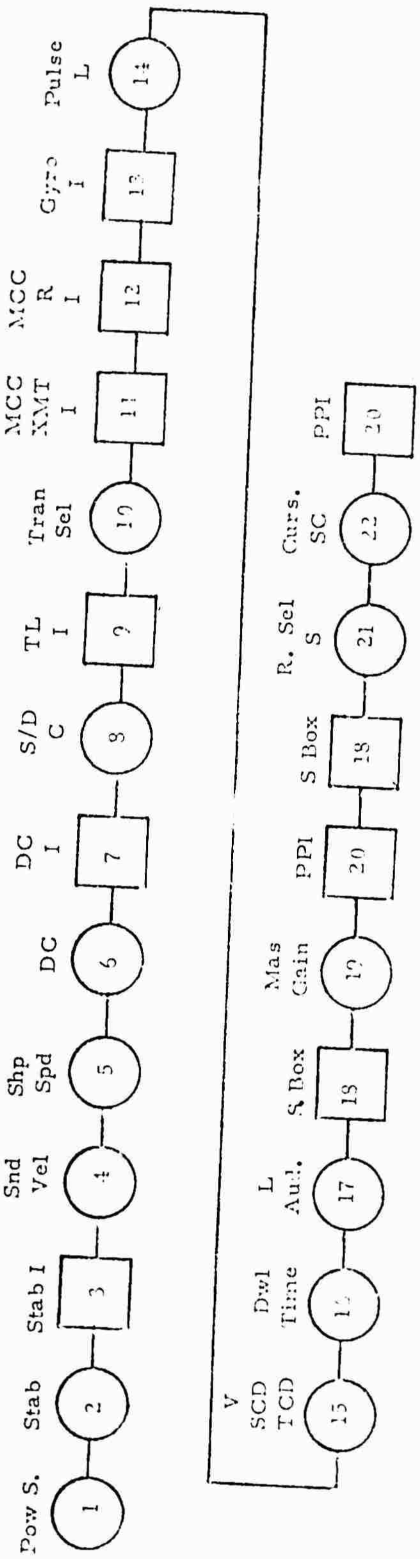


Figure [illegible].2 Operations Flow-Chart for the 14E3 Set-up Sub-Task (Revised)

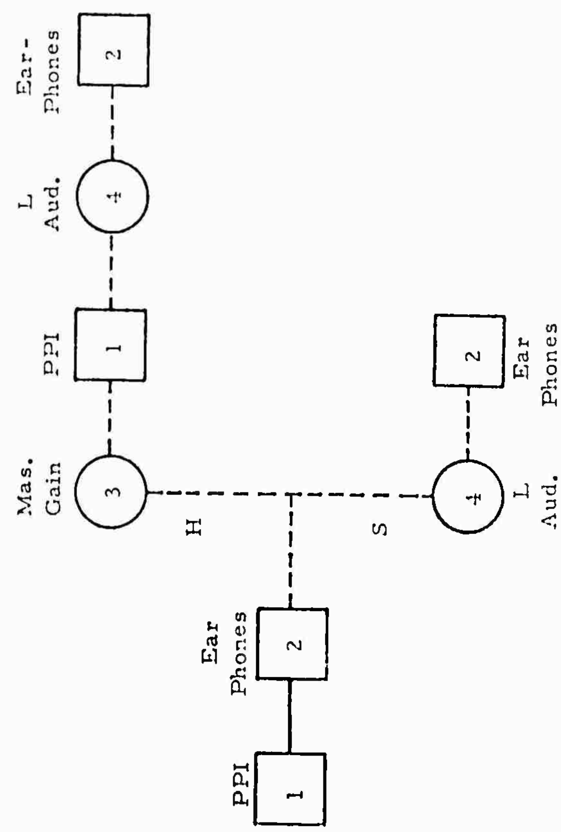


Figure 2.3. Operations Flow-Chart for the 14E3 Detection Sub-Task

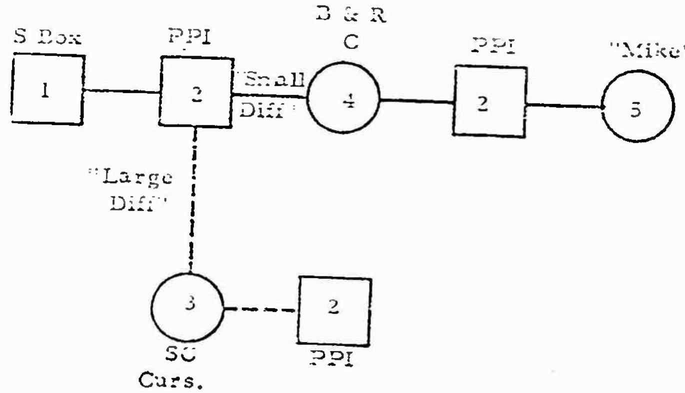


Figure [illegible]. Operations Flow-Chart for the 14E3 Localization Sub-Task

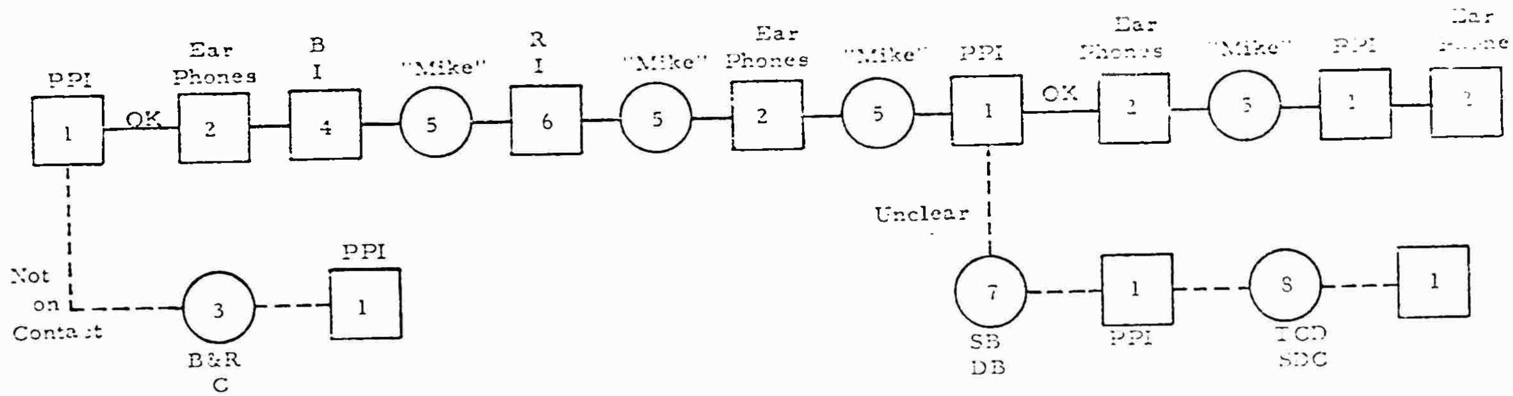


Figure 2.5 Operations Flow-Chart for the 1/4/5 Classification Sub-Task

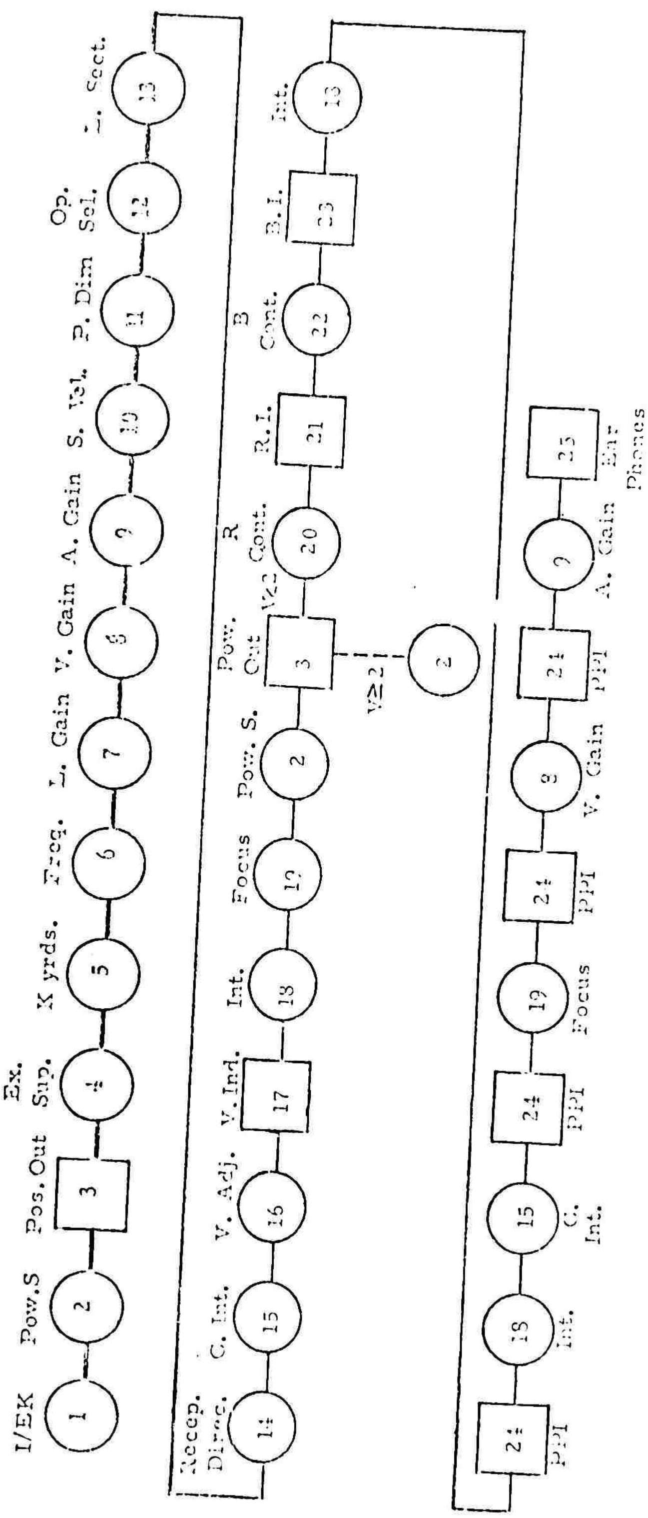


Figure 2.[illegible]. Operations Flow-Chart for the [illegible] Set-up Sub-Task

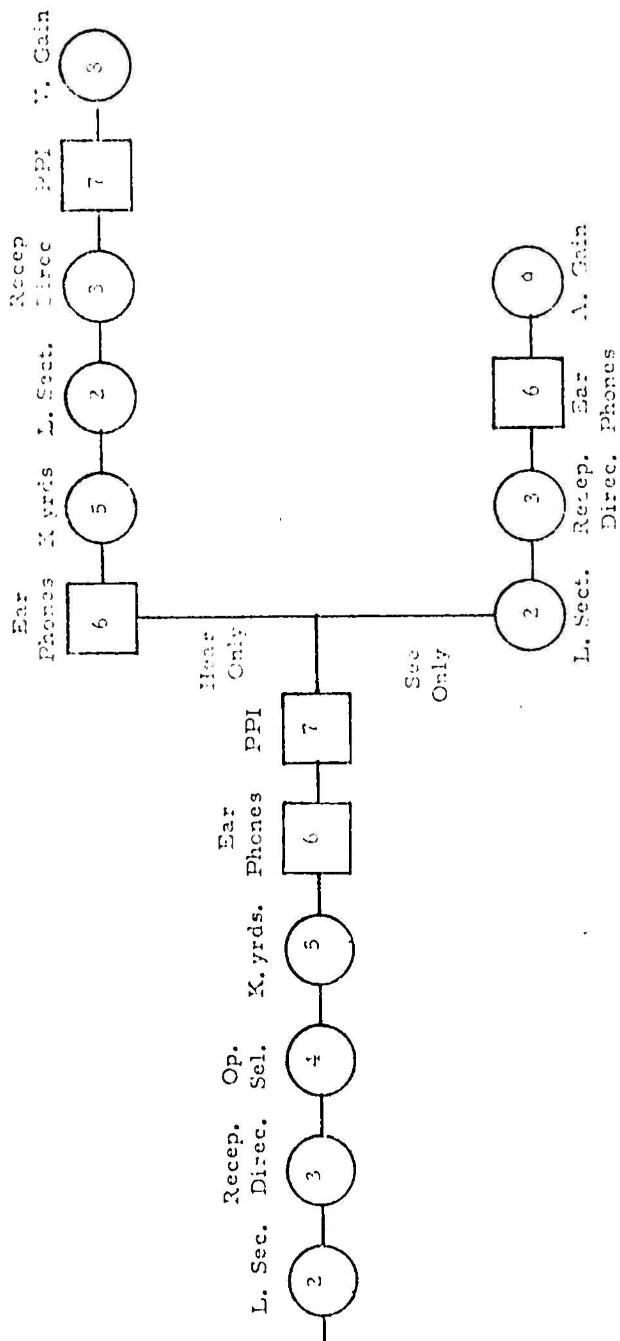


Figure 2.7. Operations Flow-Chart for the [illegible] Detection Sub-Task

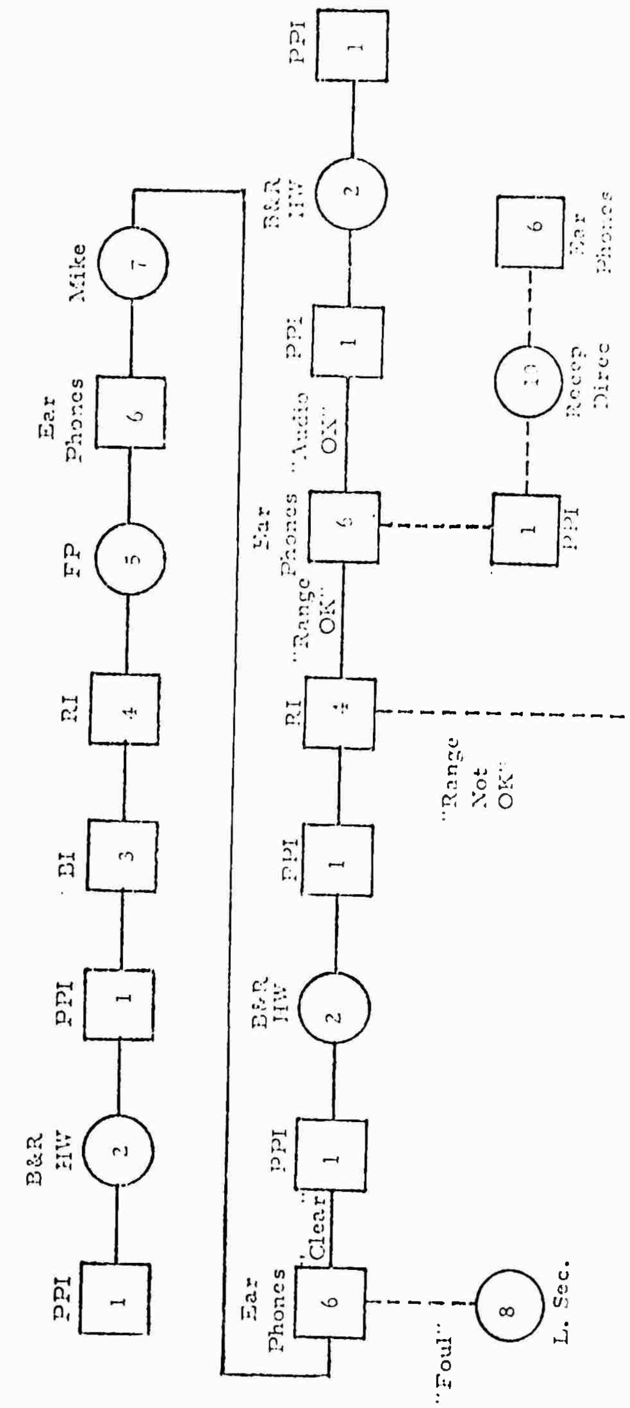


Figure 2.[illegible]. Operations Flow-Chart for the B&R Localization Sub-Task

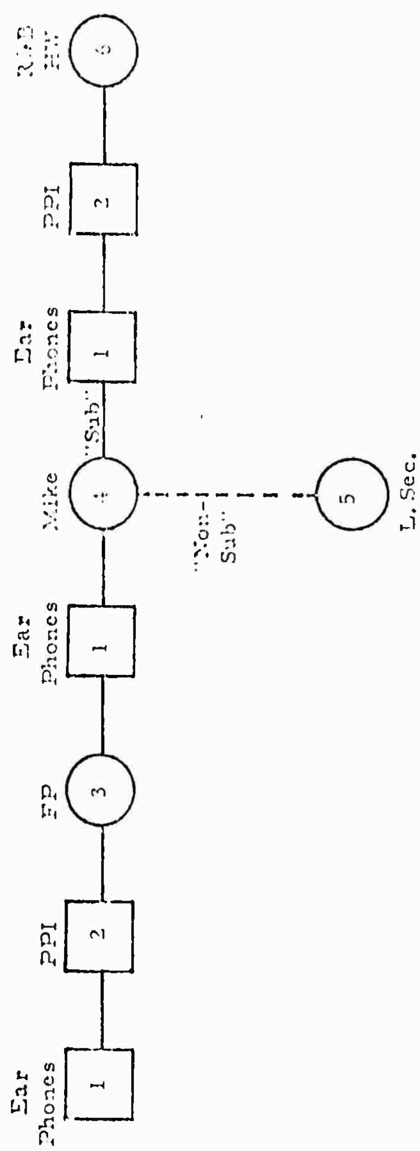


Figure 2.9. Operations Flow-Chart for the 14E10 Classification Sub-Task.

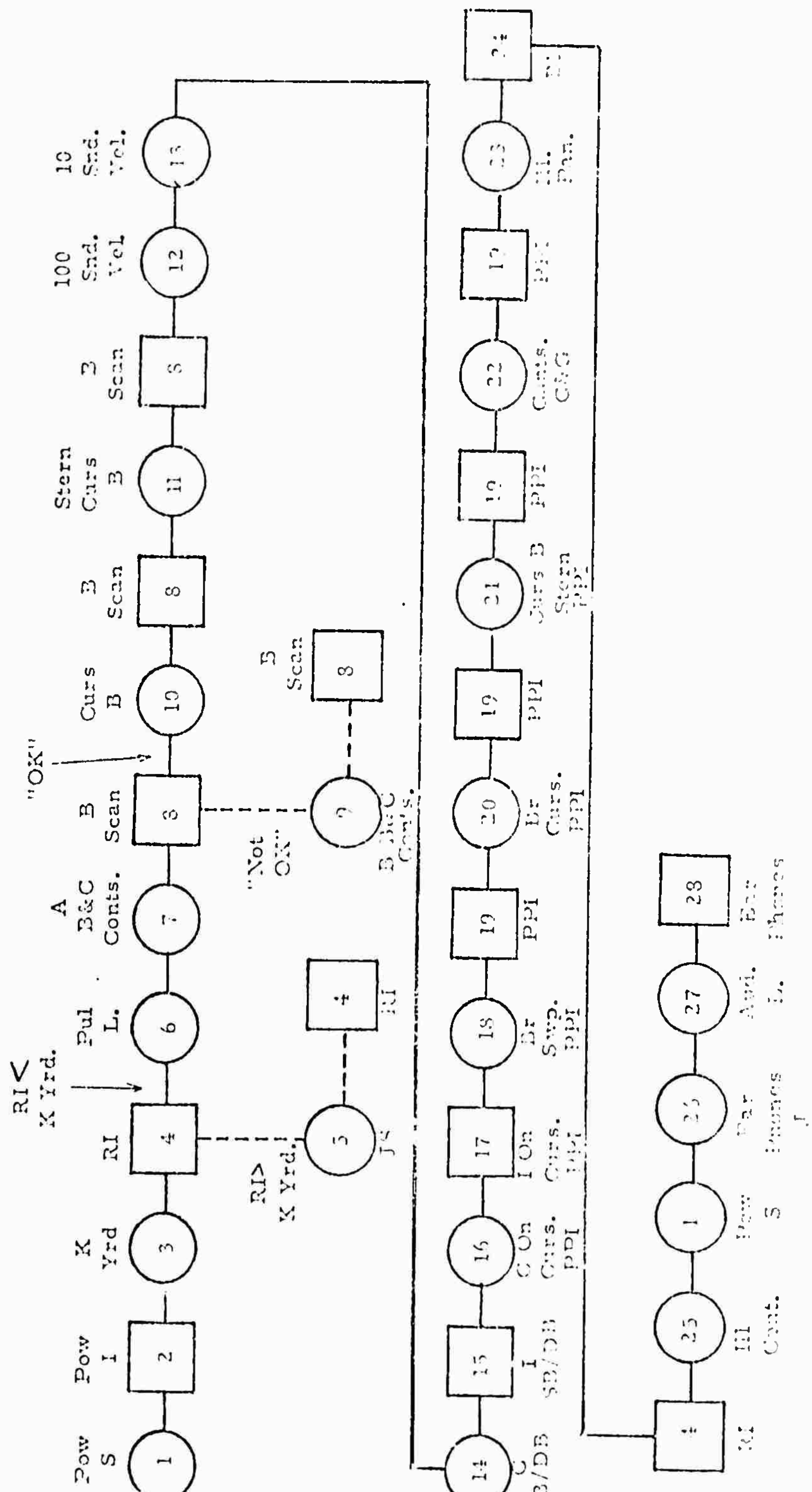


Figure 2.10. Operations Flow-Chart for the AN/SQS-26CX Set-Up Sub-Task.

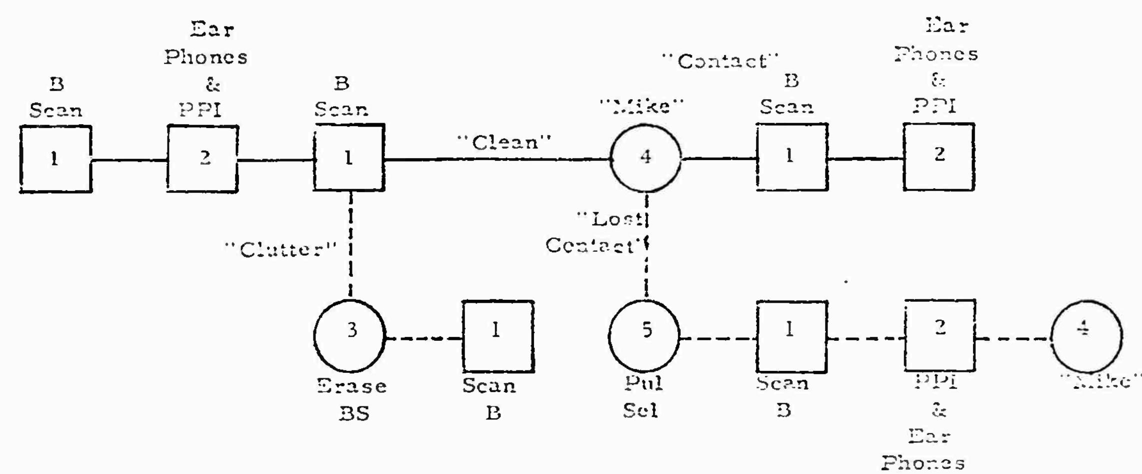


Figure 2.11. Operations Flow-Chart for the AN/SQS-26CX Detection and Lost Contact Sub-Task

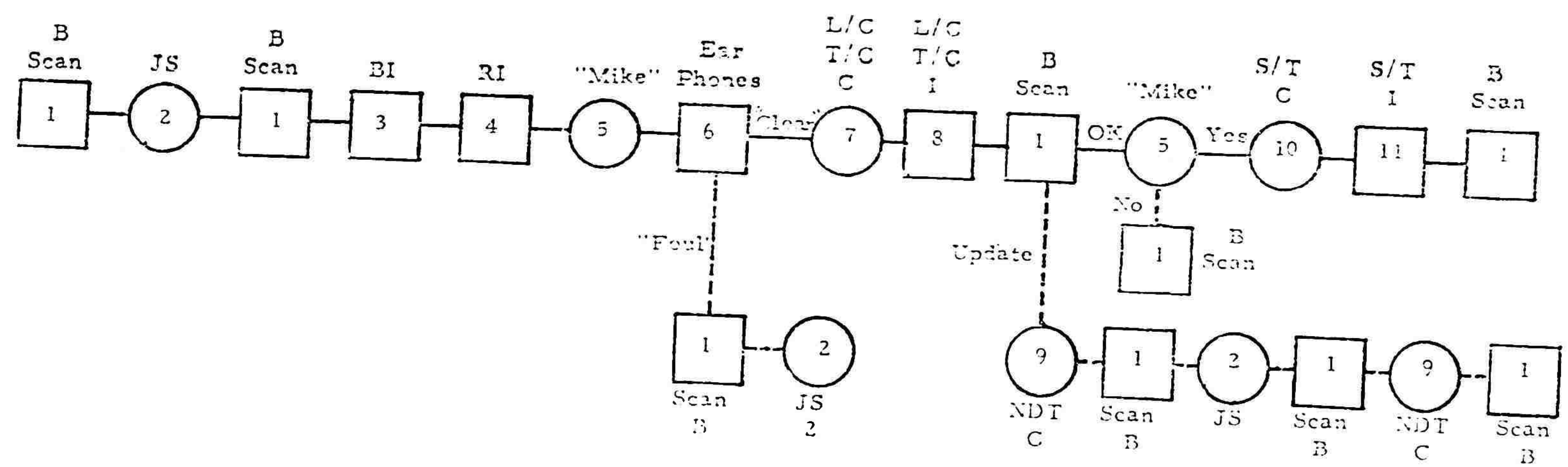


Figure 2.12. Operations Flow-Chart for the AN/SQS-26CX Localization and Tracking Sub-Task

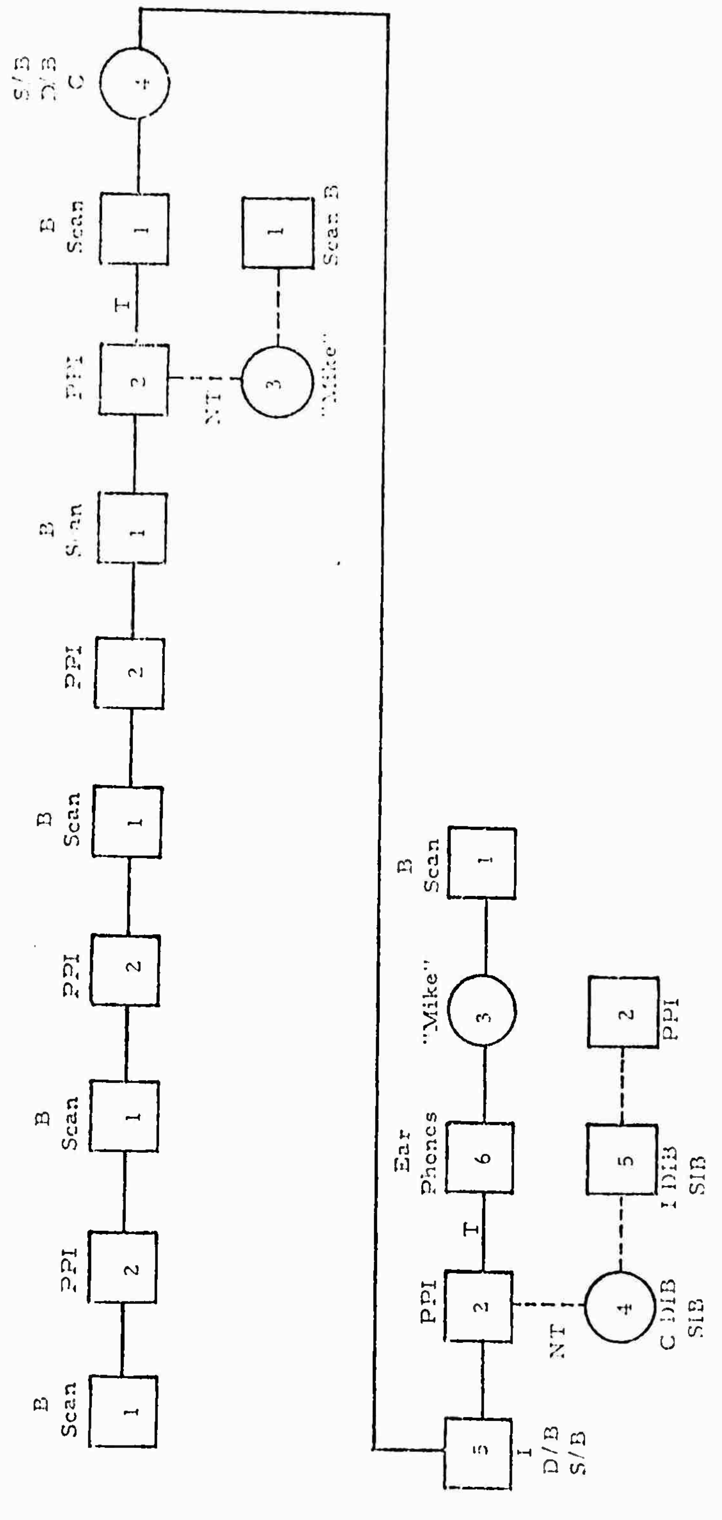


Figure 2.13. Operations Flow-Chart for the AN/SQS-26CX Classification Sub-Task.

Appendix C

DEI Link Charts

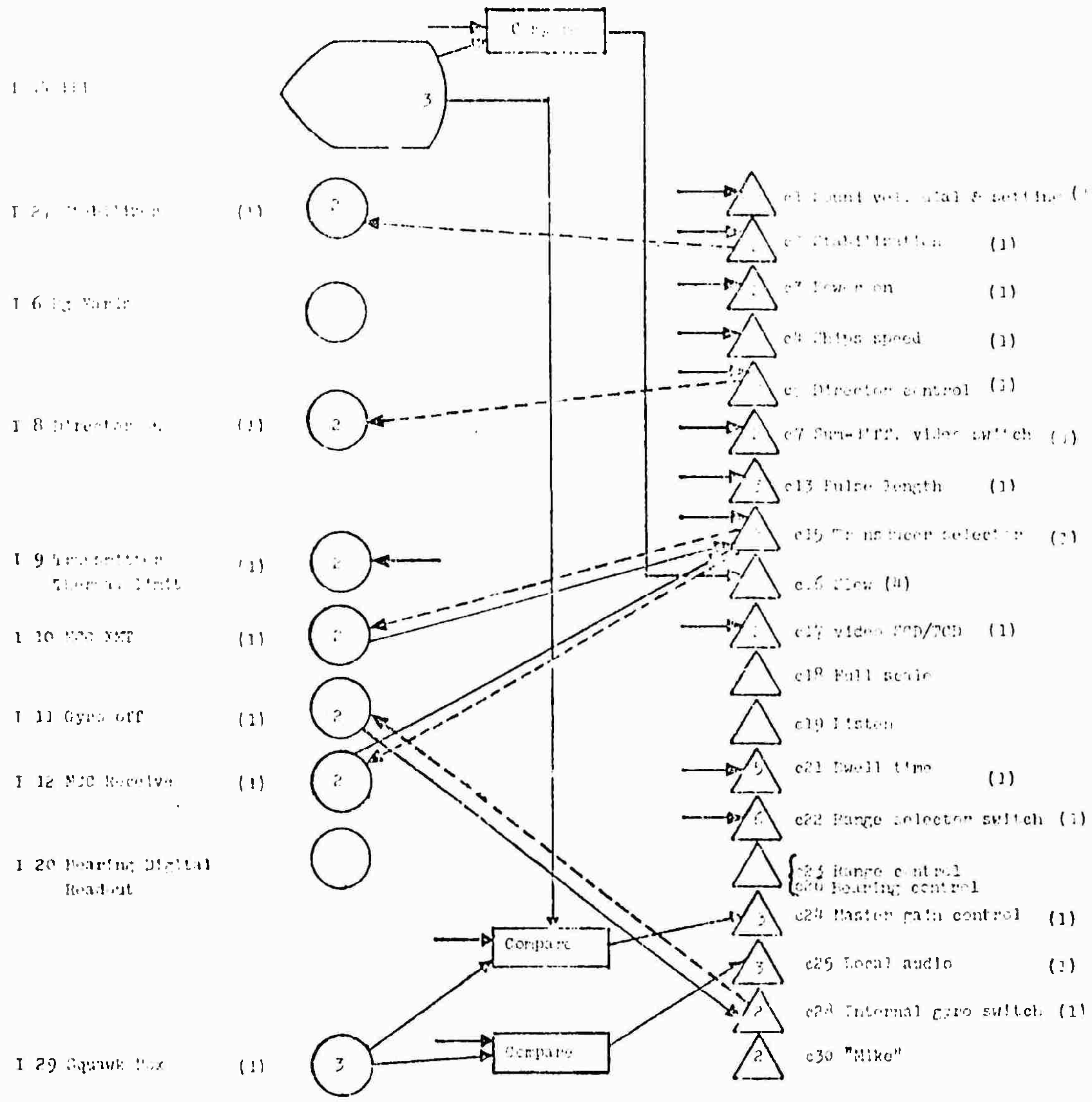


Figure 3.1. IAE3 Set-Up (original) Link Chart

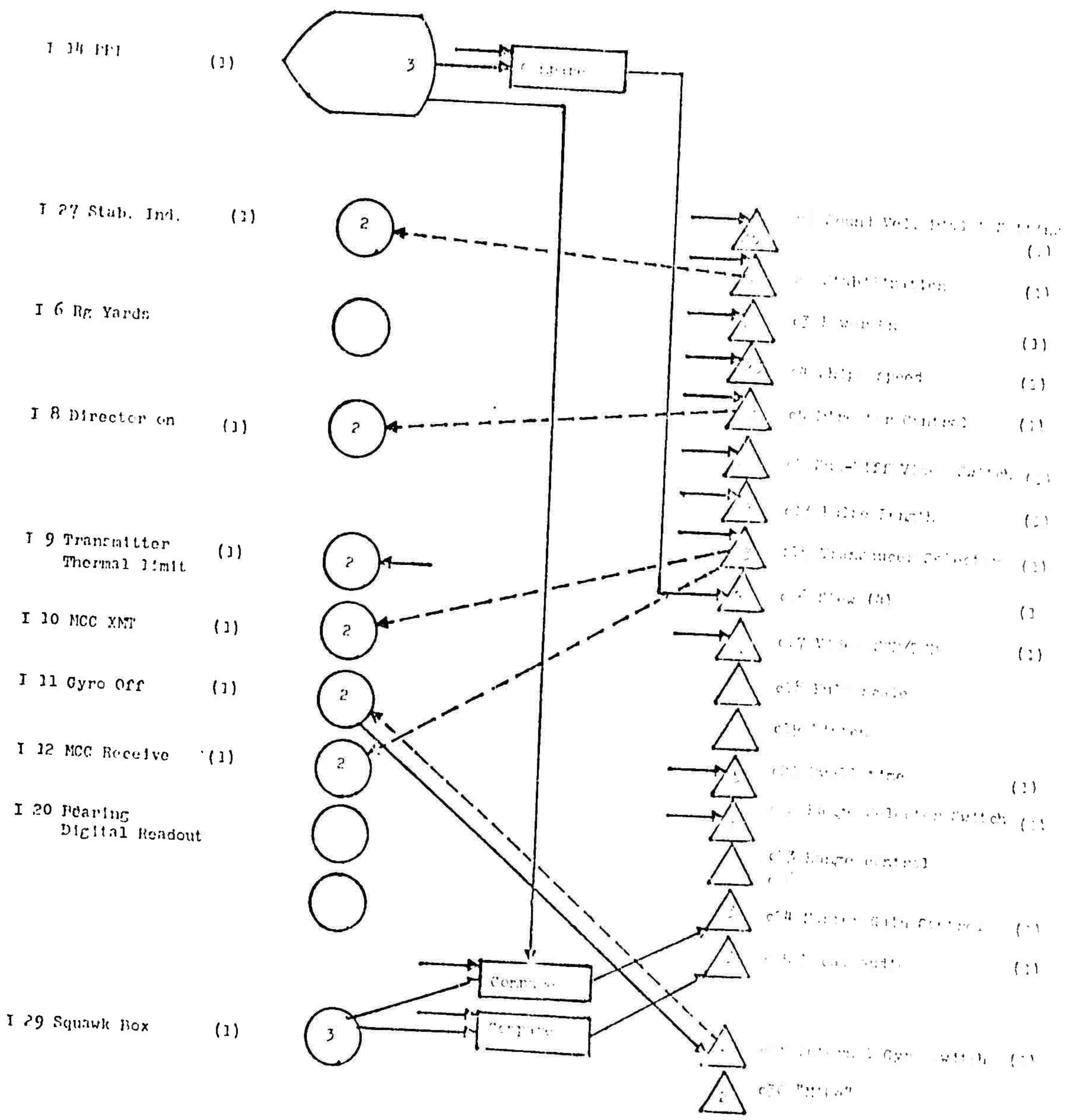


Figure 3.2. [illegible] Set-Up (revised) [illegible]

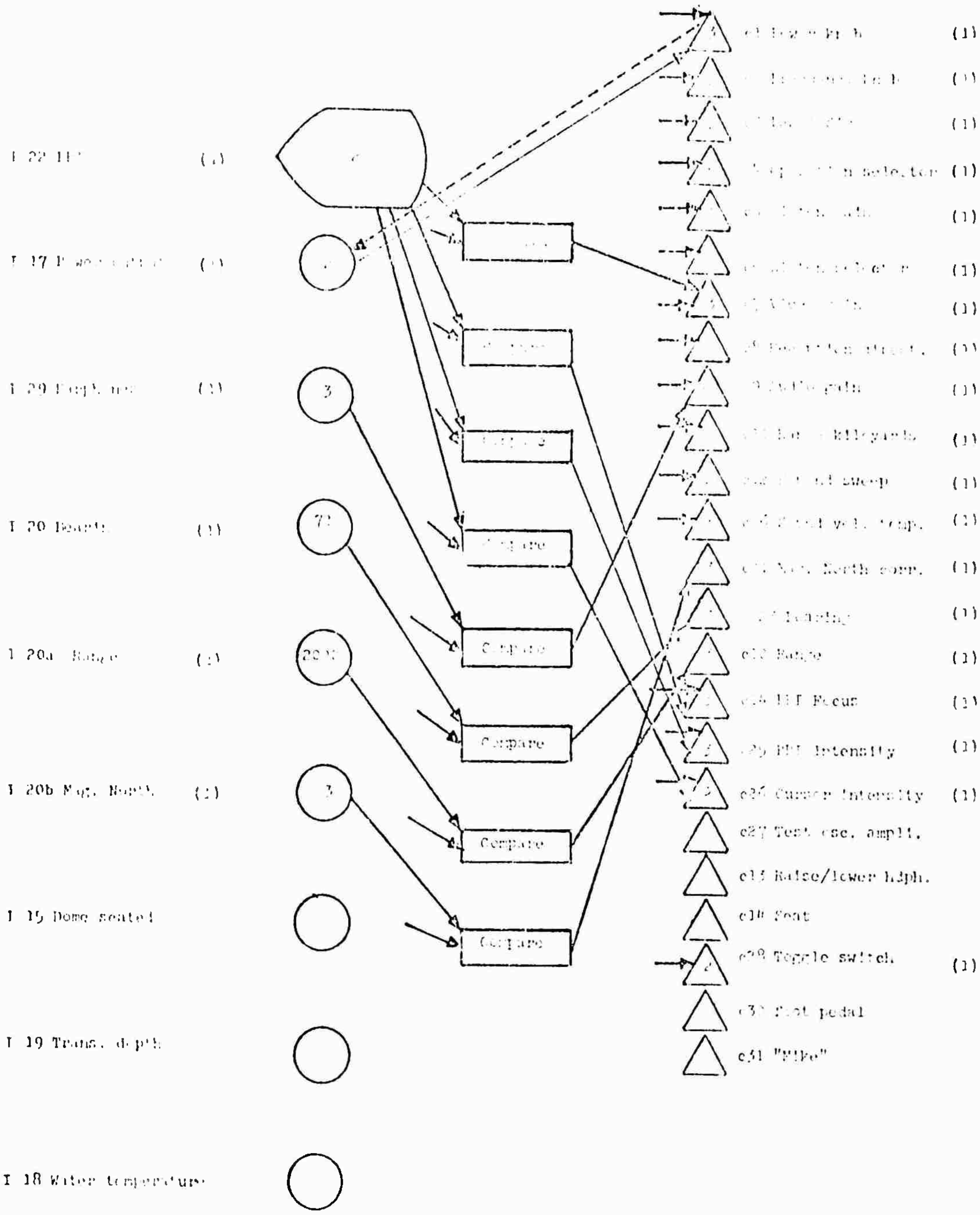
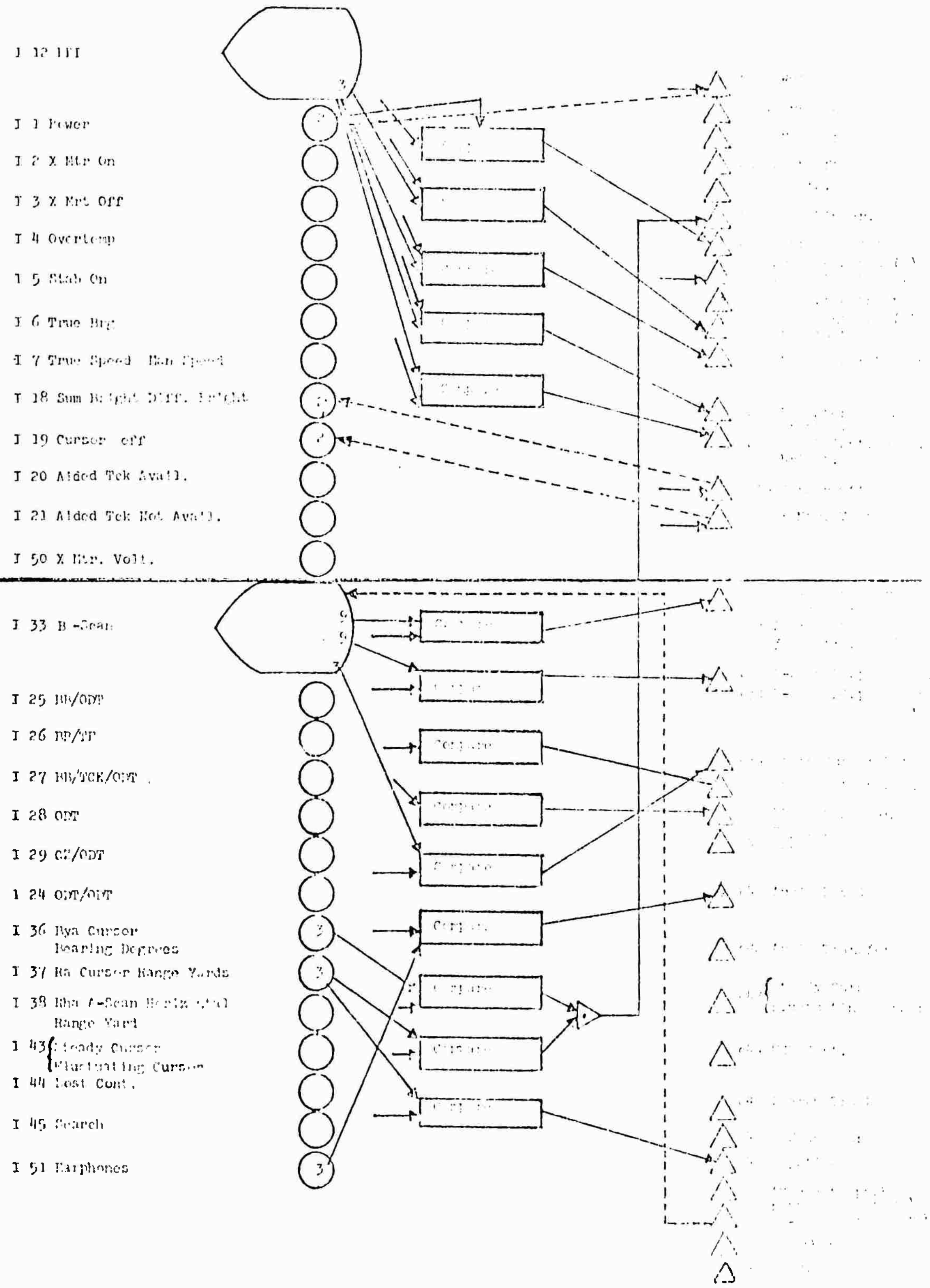


Figure 2.3. IASW Set-Up Link Chart



I 12 PPI
I 1 Power
I 2 X Mtr On
I 3 X Mrt Off
I 4 Overtemp
I 5 Stab On
I 6 True Brg
I 18 Sum Bright Diff. Bright
I 19 Cursor off
I 20 Aided Tck Avail.
I 21 Aided Tck Not Avail.
I 50 X Mtr. Volt.
I 33 B -Scan
I 25 BB/ODT
I 26 BB/TP
I 27 BB/TCK/ODT
I 28 ODT
I 29 CZ/ODT
I 24 ODT/OPT
I 36 Bya Cursor Bearing Degrees
I 37 Ra Cursor Range Yards
I 38 Rha A-Scan Horizontal Range Yard
I 43 Steady Cursor Fluctuating Cursor
I 44 Lost Cont.
I 45 Search
I 51 Earphones

Figure 3.4. [illegible]

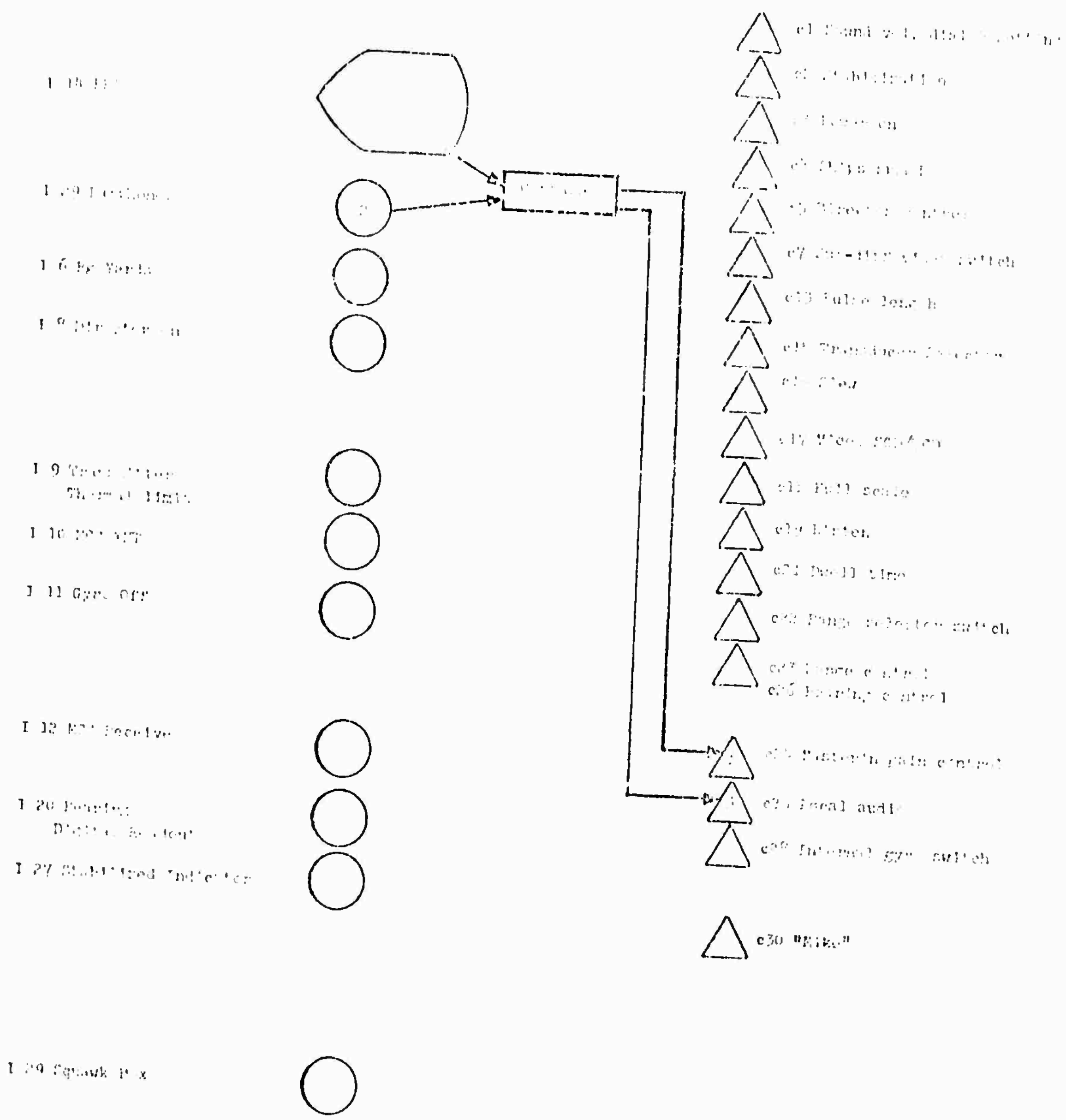


Figure 3.5. 1A63 Detection Link Chart

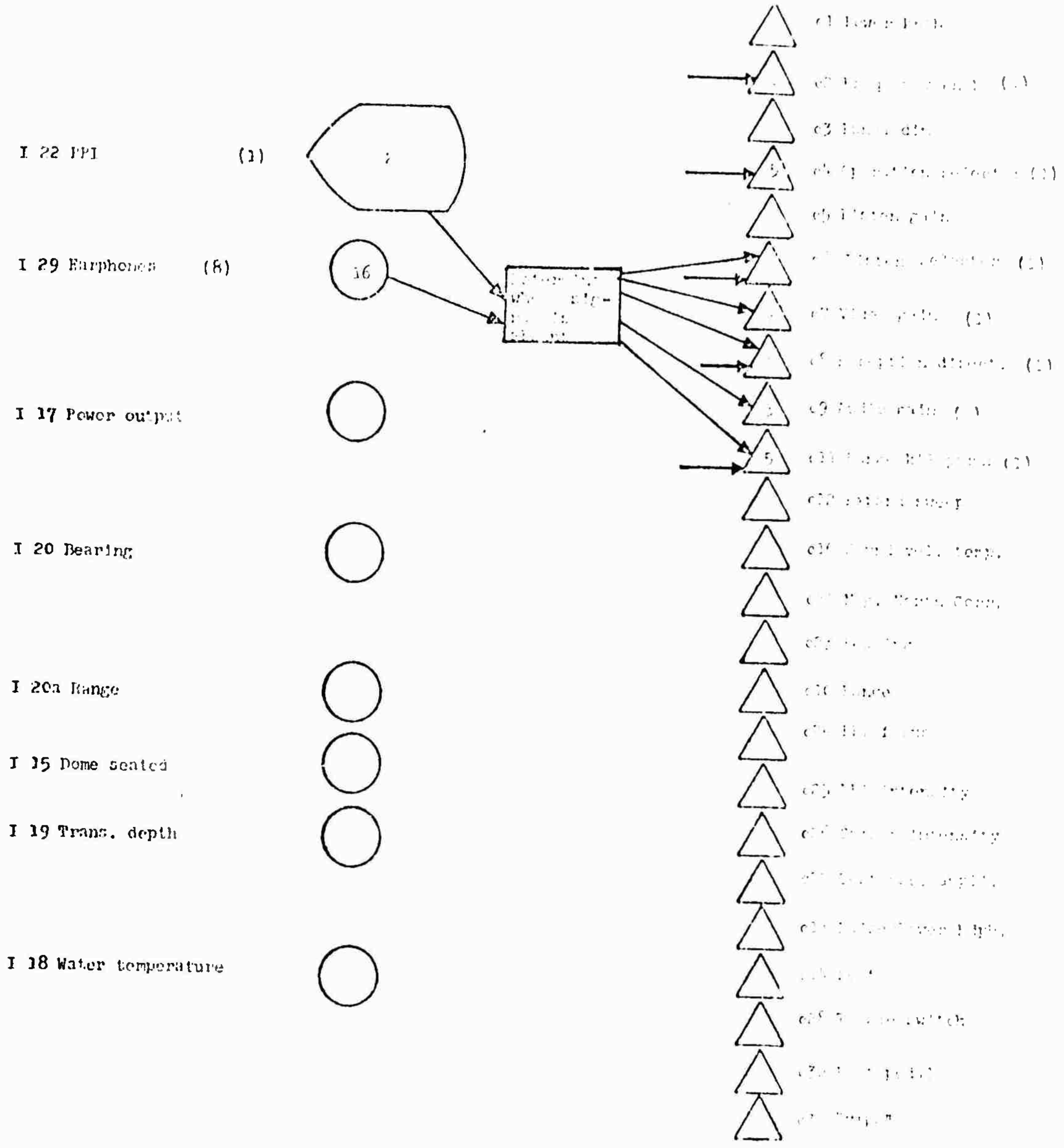


Figure 3.6. [illegible] Detection [illegible]

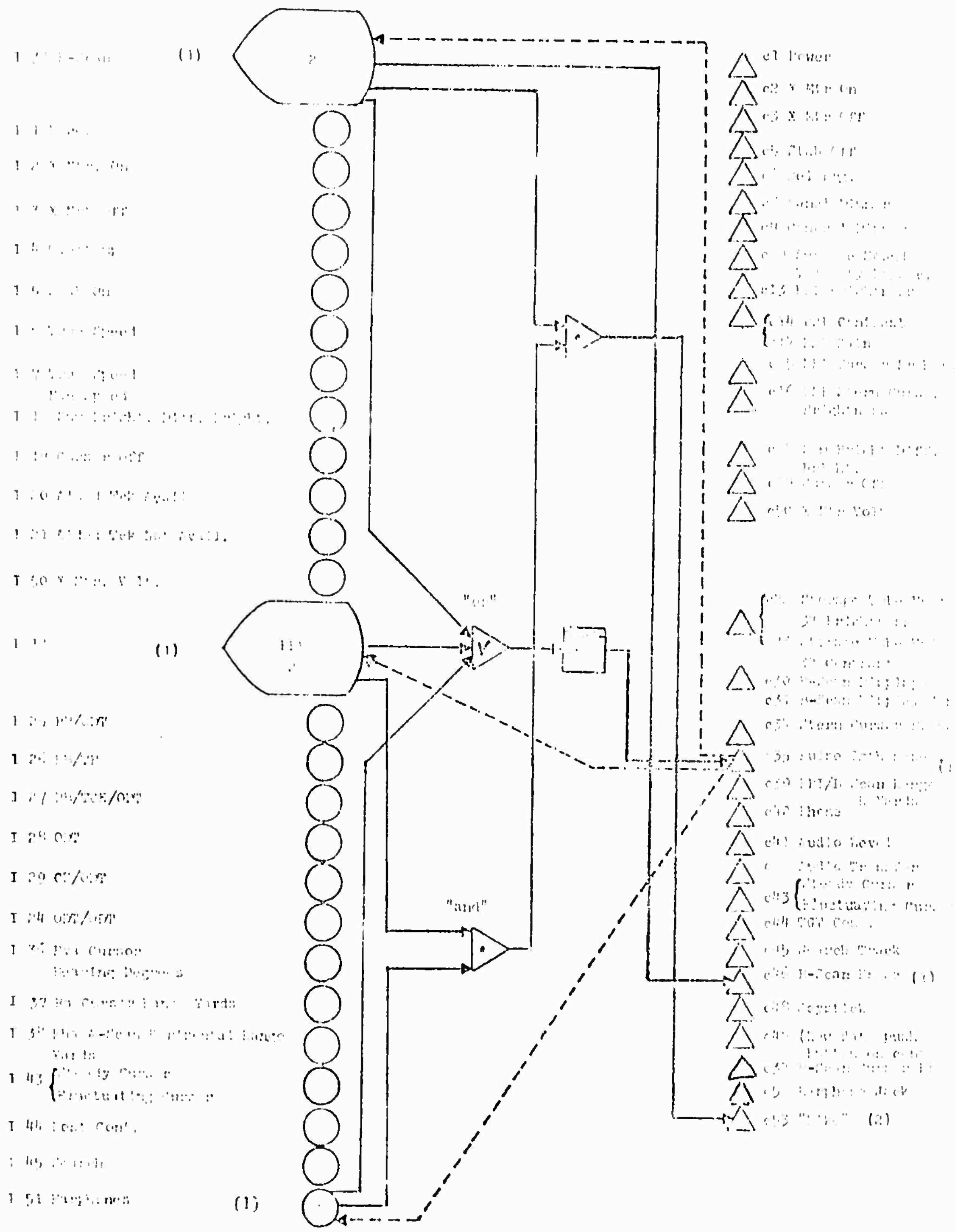


Figure [illegible] /SQS-[illegible] Detection Link Chart

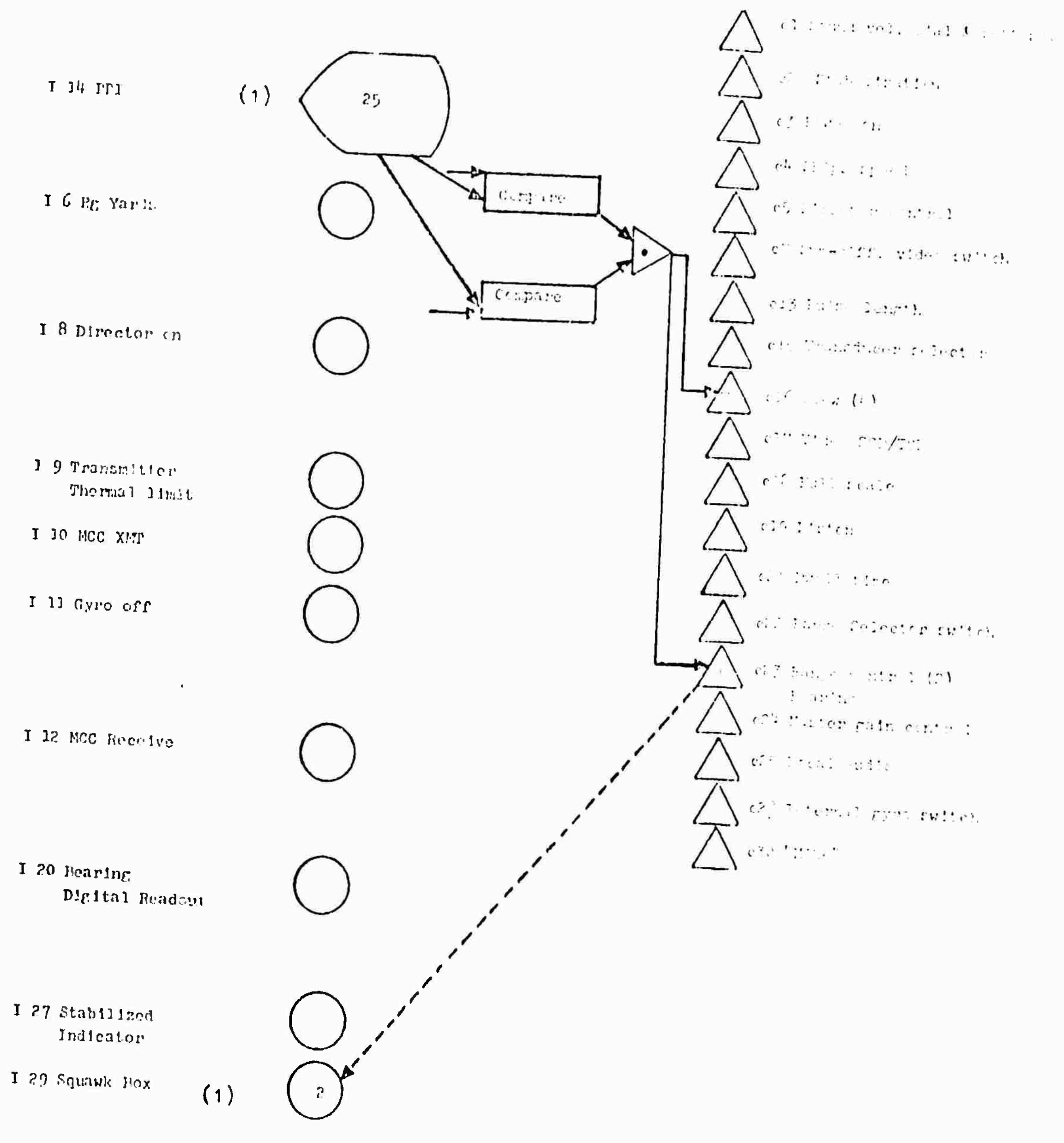


Figure 3.9. 1AE3 Localization Link ...

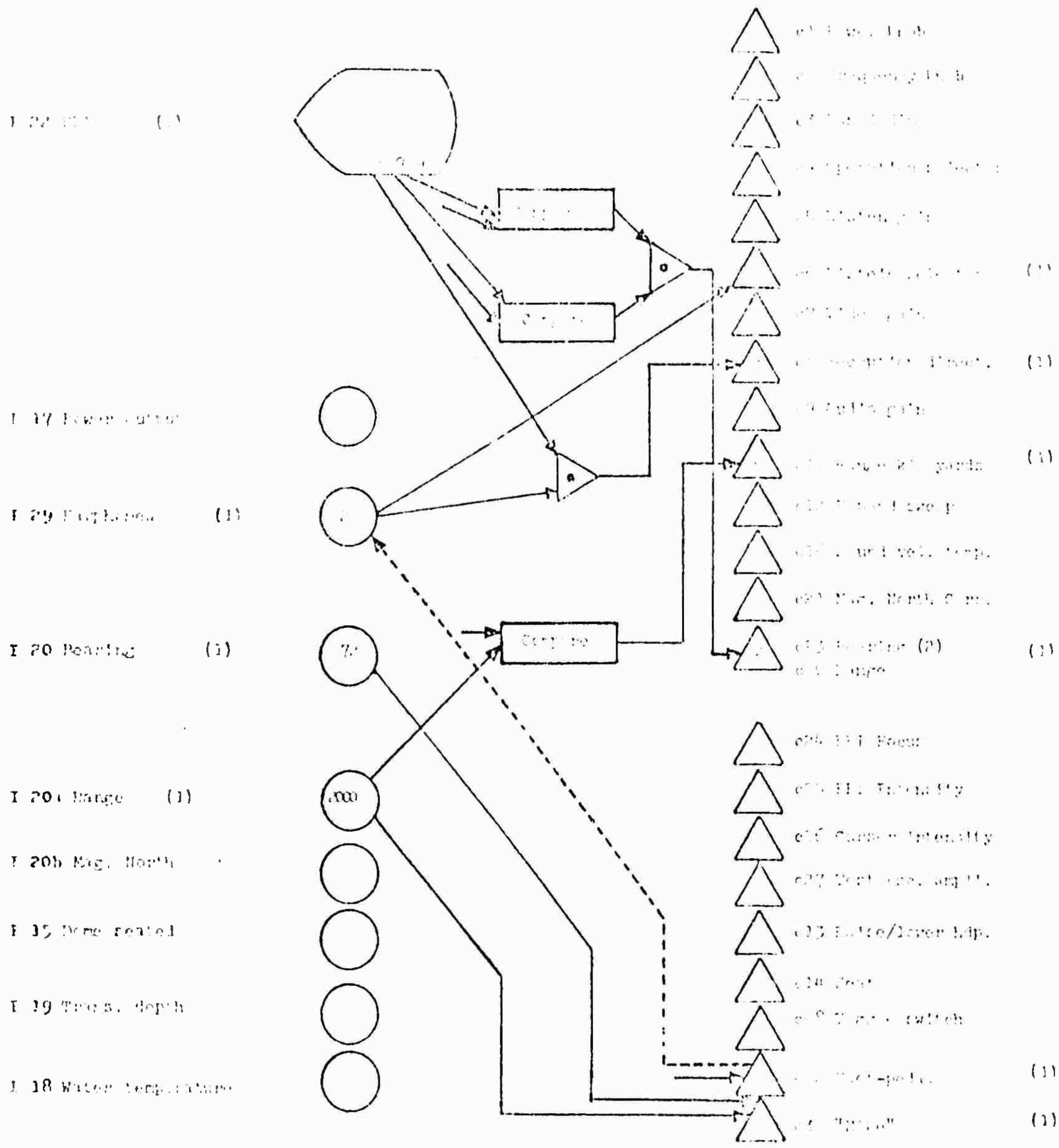


Figure [illegible] Localization Link Chart

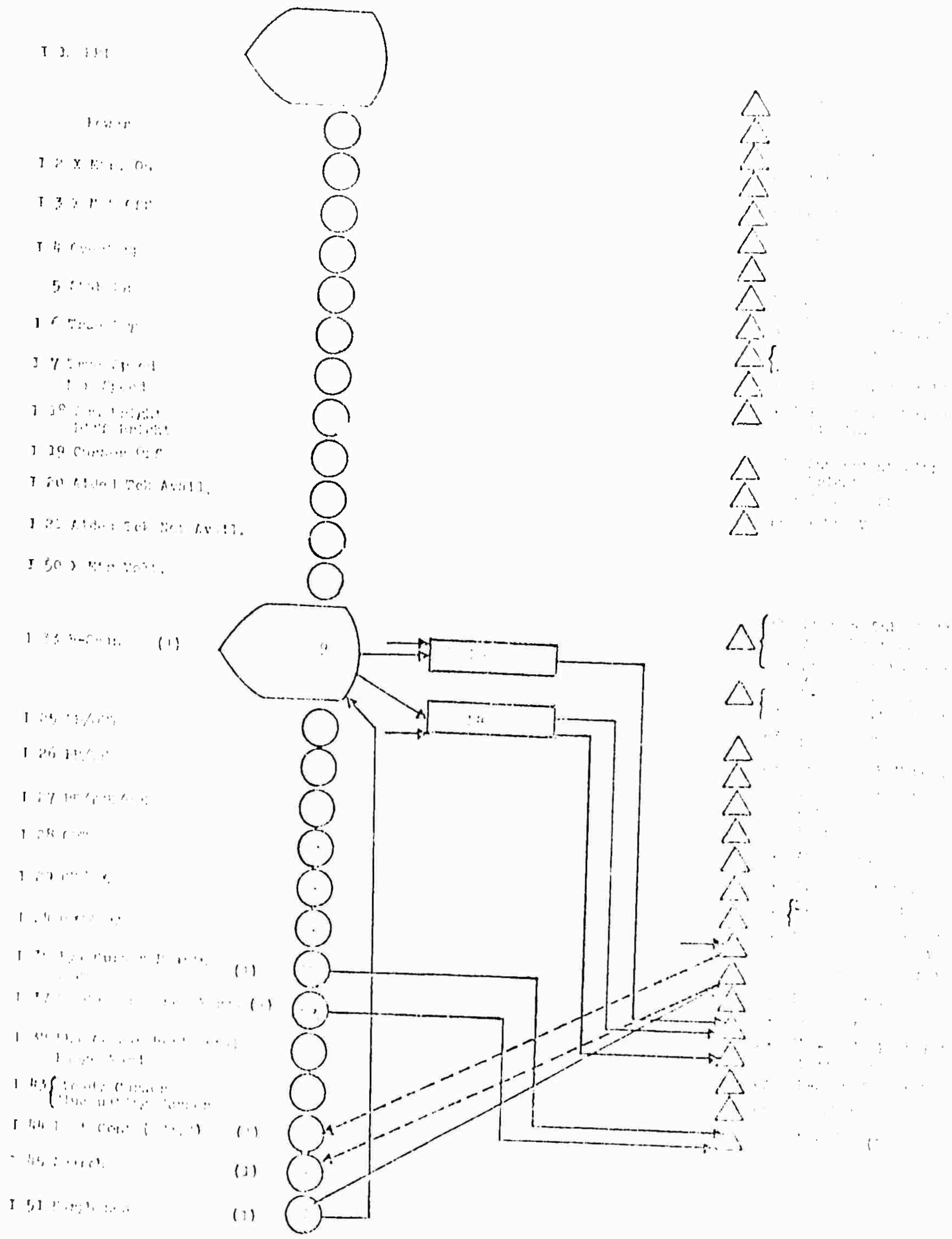


Figure 3.3[illegible].

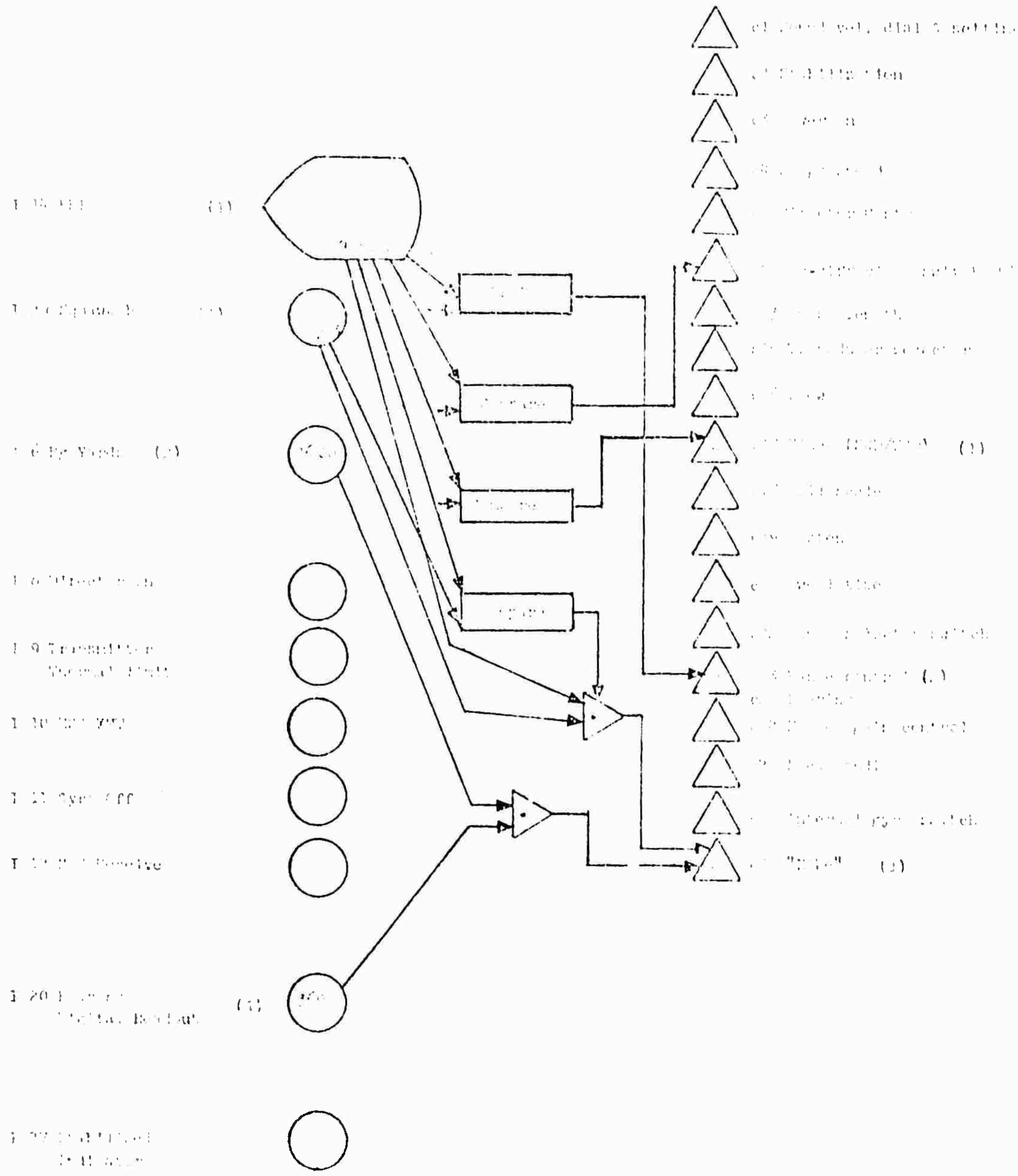


Figure [illegible].11. [illegible] Classification Link [illegible]

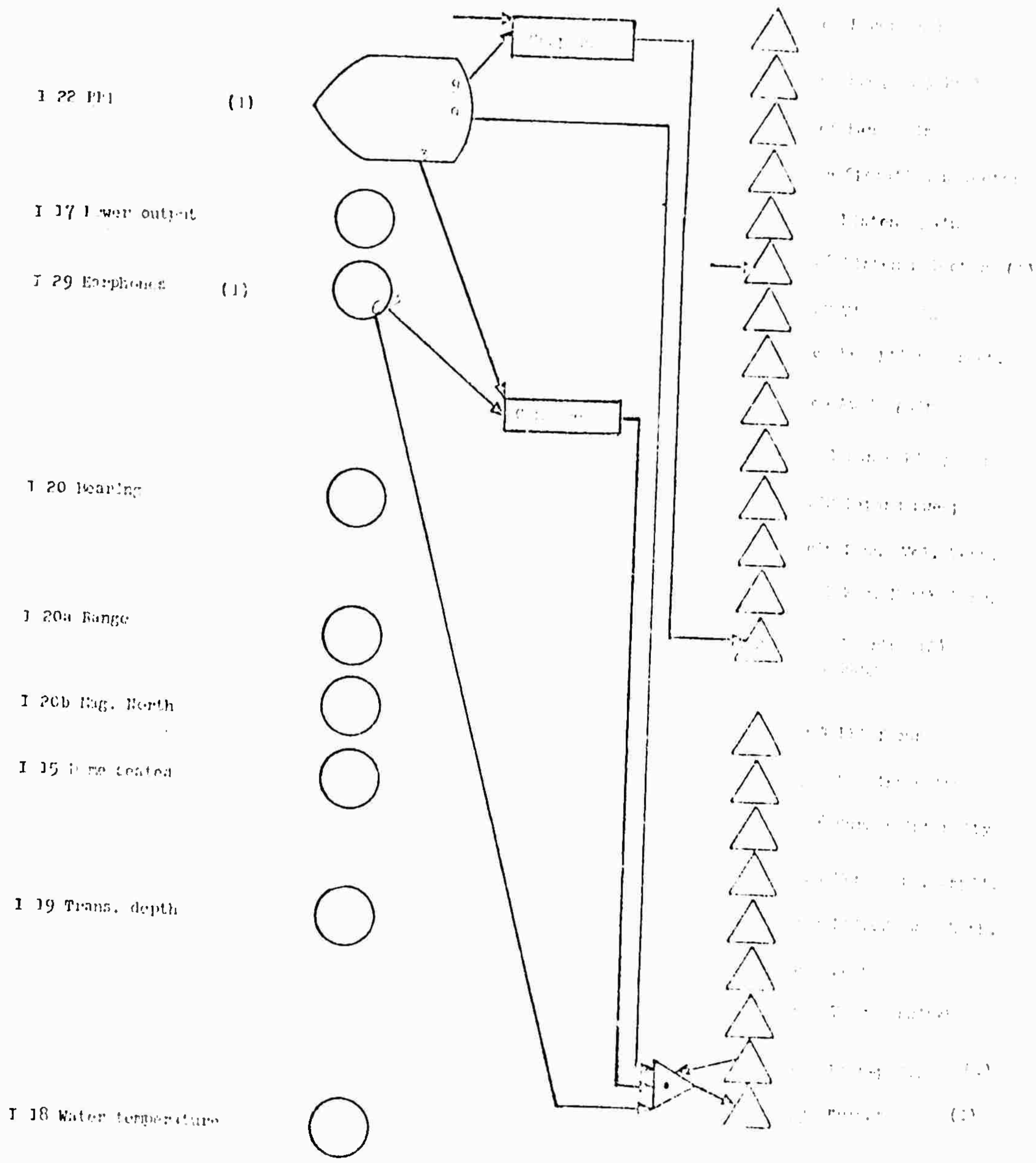
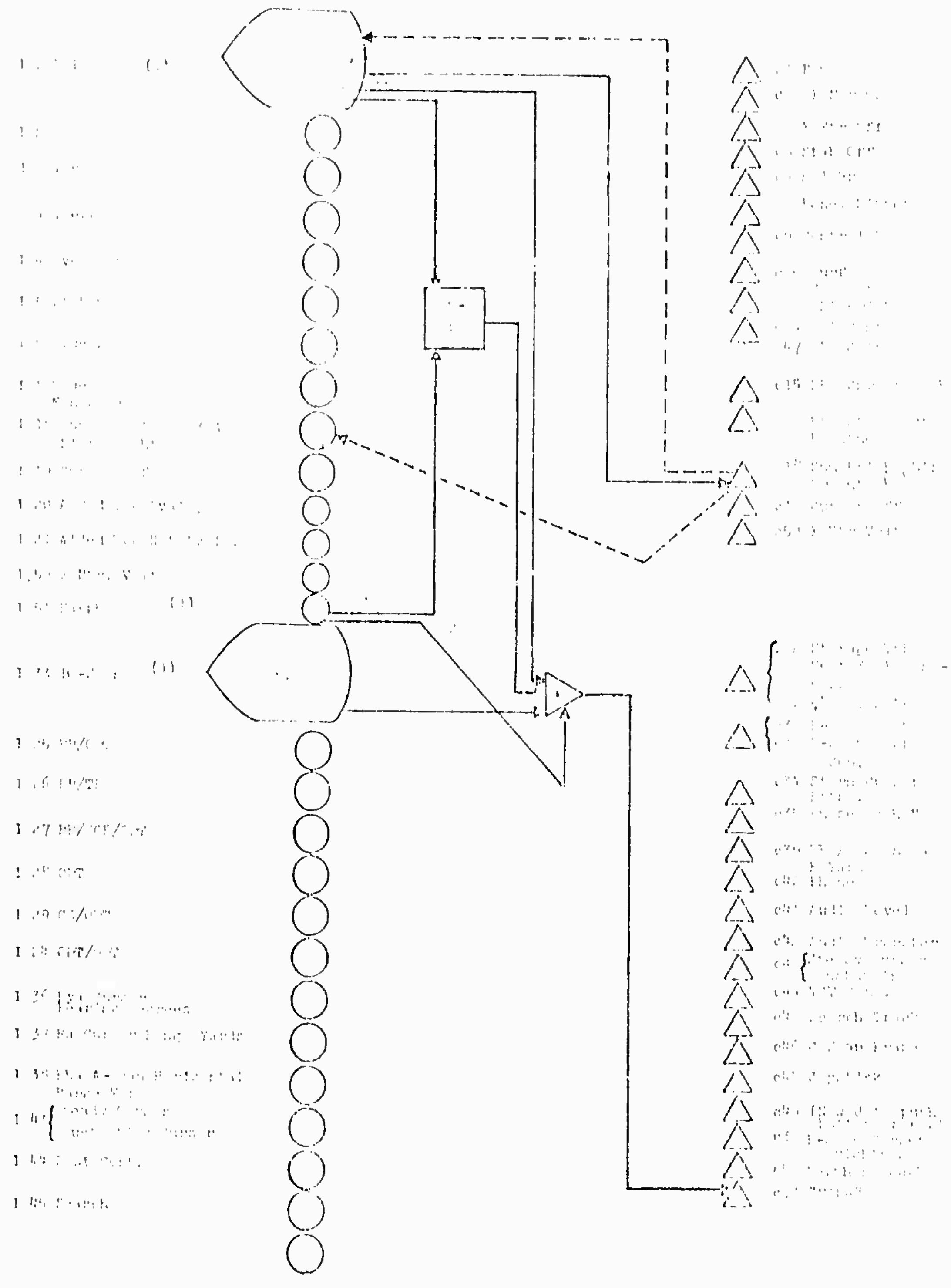


Figure 3.12. [illegible] Classification [illegible]



[illegible]

Appendix D

Prediction Study References

Prediction References

Adams, J. A. Psychomotor performance as a function of intertrial rest interval. *Journal of Experimental Psychology*, 1954, *48*, 131-133.

Ammons, R. B., Farr, R. G., Bloch, E., Neumann, E., Dey, M., Marion, R., & Ammons, C. H. Long term retention of perceptual-motor skills. *Journal of Experimental Psychology*, 1958, *55*, 318-328.

Archer, E. J., Kent, G. W., & Mote, F. A. Effect of long-term practice and time-on-target information feedback on a complex tracking task. *Journal of Experimental Psychology*, 1956, *51*, 103-112.

Bilodeau, E. A. Some effects of various degrees of supplemental information given at two levels of practice upon the acquisition of a complex motor skill. Research Bulletin 52-15, April 1952, Human Resources Research Center, Lackland Air Force Base, San Antonio, Texas.

Birren, J. E., & Fisher, M. B. Standardization of two tests of hand-eye coordination: A two-hand complex tapping test and a rotary pursuit test. Research Project X-295, Report No. 6, 1945, NMRI, Bethesda, Maryland.

Briggs, G. E., Fitts, P. M., & Bahrick, H. P. Learning and performance in a complex tracking task as a function of visual noise. Research Report AFPTRC-TN-56-67, June 1956, Air Force Personnel and Training Research Center, Lackland Air Force Base, Texas.

Brown, C. W., Ghiselli, E. E., Jarrett, R. F., Minium, E. W., & U'Ren, R.M. Comparison of aircraft controls for prone and seated position in three-dimensional pursuit task. AF Technical Report No. 5956, October 1949, United States Air Force Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio.

Cook, B. S., & Hilgard, E. R. Distributed practice in motor learning: Progressively increasing and decreasing rests. *Journal of Experimental Psychology*, 1949, *39*, 169-172.

Dore, L. R., & Hilgard, E. R. Spaced practice and maturation hypothesis. *The Journal of Psychology*, 1937, *4*, 245-259.

Fleishman, E. A. Unpublished data on two-hand coordinator.

Fleishman, E. A., & Rich, S. Role of kinesthetic and spatial-visual abilities in perceptual-motor learning. _Journal of Experimental Psychology_, 1963, _66_, 6-11.

Gagne, R. M., & Bilodeau, E. A. The effects of target size variation on skill acquisition. Research Bulletin AFPTRC-TR-54-5, April 1954, Air Force Personnel and Training Research Center, Lackland Air Force Base, San Antonio, Texas.

Goldstein, M., & Rittenhouse, C. H. The effects of practice with triggering omitted on performance of the total pedestal sight gunnery task. Technical Report 53-9, May 1953, Human Resources Research Center, Lackland Air Force Base, San Antonio, Texas.

Howland, D., & Merrill, E. N. The effect of physical constants of a control on tracking performance. _Journal of Experimental Psychology_, 1953, _46_, 353-360.

Leonard, S. D., Karnes, E. W., Oxendine, J., & Hesson, J. Effects of task difficulty on transfer performance on rotary pursuit. _Perceptual and Motor Skills_, 1970, _30_, 731-736.

Lewis, D., & Shephard, A. H. Devices for studying associative interference in psychomotor performance. IV. The turret pursuit apparatus. _The Journal of Psychology_, 1950, _29_, 173-82.

Lincoln, R. S. Learning and retaining a rate of movement with the aid of kinesthetic and verbal cues. _Journal of Experimental Psychology_, 1956, _51_, 199-204.

Noble, C. E. An attempt to manipulate incentive motivation in a continuous tracking task. Research Bulletin AFPTRC-TR-54-13, October 1954, Air Force Personnel and Training Research Center, Lackland Air Force Base, San Antonio, Texas.

Reynolds, B., & Adams, J. A. Effect of distribution and shift in distribution of practice within a single training session. _Journal of Experimental Psychology_, 1953, _46_, 137-145.

Reynolds, B., & Bilodeau, I. M. Acquisition and retention of three psychomotor tests as a function of distribution of practice during acquisition. USAF Human Resources Research and Development, Lackland Air Force Base, San Antonio, Texas.

Spieth, W. An investigation of individual susceptibility to interference in the performance of three psychomotor tasks. Research Bulletin, 53-8, April 1953, Human Resources Research Center, Lackland Air Force Base, San Antonio, Texas.*

*This study yielded two groups and hence two sets of learning data for the post-diction study.

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13. ABSTRACT

An exploratory study was undertaken, as part of a program to develop quantitative techniques for prescribing the design and use of training systems. As a first step in this program, the present study attempted to (1) compile an initial set of quantitative indices, (2) determine whether these indices could be used to describe a sample of trainee tasks and differentiate among them, (3) develop a predictive methodology [illegible] that methodology using [illegible] the literature.

The compilation included the [illegible] lay-out indices, and a set of task rating scales. [illegible] task analytic data, collected on sonar operator [illegible] Sonar School, Key West, Florida. Application of the indices [illegible], and differentiation among three training devices, and within four trainee [illegible] (set up, detection, localization, classification) was possible.

The predictive method which was generated was an adaptation of the standard multiple regression model. Mean [illegible] scores replaced the usual individual criterion scores, and quantitative task [illegible] were used as predictor scores. This adaptation was tested using data from published studies [illegible]. Significant multiple correlations using task indices were found for criterion data obtained during early stages of practice. [illegible] training indices did predict later performance. This result supports the contention that a prescriptive method must include "training" [illegible] indices" in order to account for advanced levels of proficiency.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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Trainee Sub-Tasks						
Quantitative Task Analysis						
Task Characteristics						
Performance Prediction						

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